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By

J. NEILS THOMPSON

and

W. D. RAMEY

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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Preface

The series of beam tests reported herein were begun April 1, 1945, by the authors for the Bureau of Engineering Research of The University of Texas and the Structural Clay Products Institute. Funds, materials, and equipment were provided for this investigation by these two organizations.

The authors wish to express their gratitude to Mr. Harry C. Plummer of the Structural Clay Products Institute, Mr. W. G. Demarest of the Clay Products Association of the Southwest, and Professor Phil M. Ferguson of the Civil Engineering Department of The University of Texas, for their helpful suggestions toward carrying on the work.

Abstract

One of the most recent developments in the building industry is the use of precast beams made of structural clay tile combined with concrete and reinforced with steel rods. The fact that no centering or form work is necessary, reduces materially the square foot cost of the assembly, and greatly simplifies its erection.

In the use of this type of construction a number of questions have been asked which can only be answered by making strength tests of typical beams. The tests reported herein were made for the purpose of answering some of the questions concerning diagonal tension stresses, buttered joints, etc.

In the first series of tests made, the resistance of a tile-concrete beam to diagonal tension stresses as compared with a concrete beam was studied. The results indicate that the concrete-tile beam carried 38 per cent more diagonal stress than did the concrete beams. This series of tests leaves no doubt concerning the strengthening of this type of beam (Economy U) by the presence of the particular tile used. The tile used in these tests had a higher tensile strength than the concrete.

By using electric strain gage rosettes, it was possible to determine the extent the outside shell helps in carrying the diagonal tension stresses. The data collected showed that the outside shell was strained very little, indicating that only small resistance was accountable to the outside shells.

In studying the relation between the observed and calculated diagonal tension stresses, it was found that the conventional formula for concrete is good, but in order to determine the stress in the tile, the stress determined by this formula must be multiplied by the ratio of modulus of elasticity of the tile to modulus of elasticity of the concrete.

Another problem was the effect of the depth of the precast concrete on the strength of the beam. In a series of tests in which different depths of precast concrete were used, it was found that for this type of tile beam (Economy U), it was necessary to leave at least one inch of tile wall at the top to develop adequate bond between the floor slab and the precast section. Subsequent tests on flush type beams, not included in this report, indicate that the channels of beams of this type may be precast to the top.

In another series of tests, with the Economy U type in which the joints in the tile were buttered, it was found that the load carrying capacity of the beams was not increased by buttering the joints.

Some specifications require that in ribbed tile construction the joints of the tile be staggered. There was no indication in these tests that this requirement is justified.

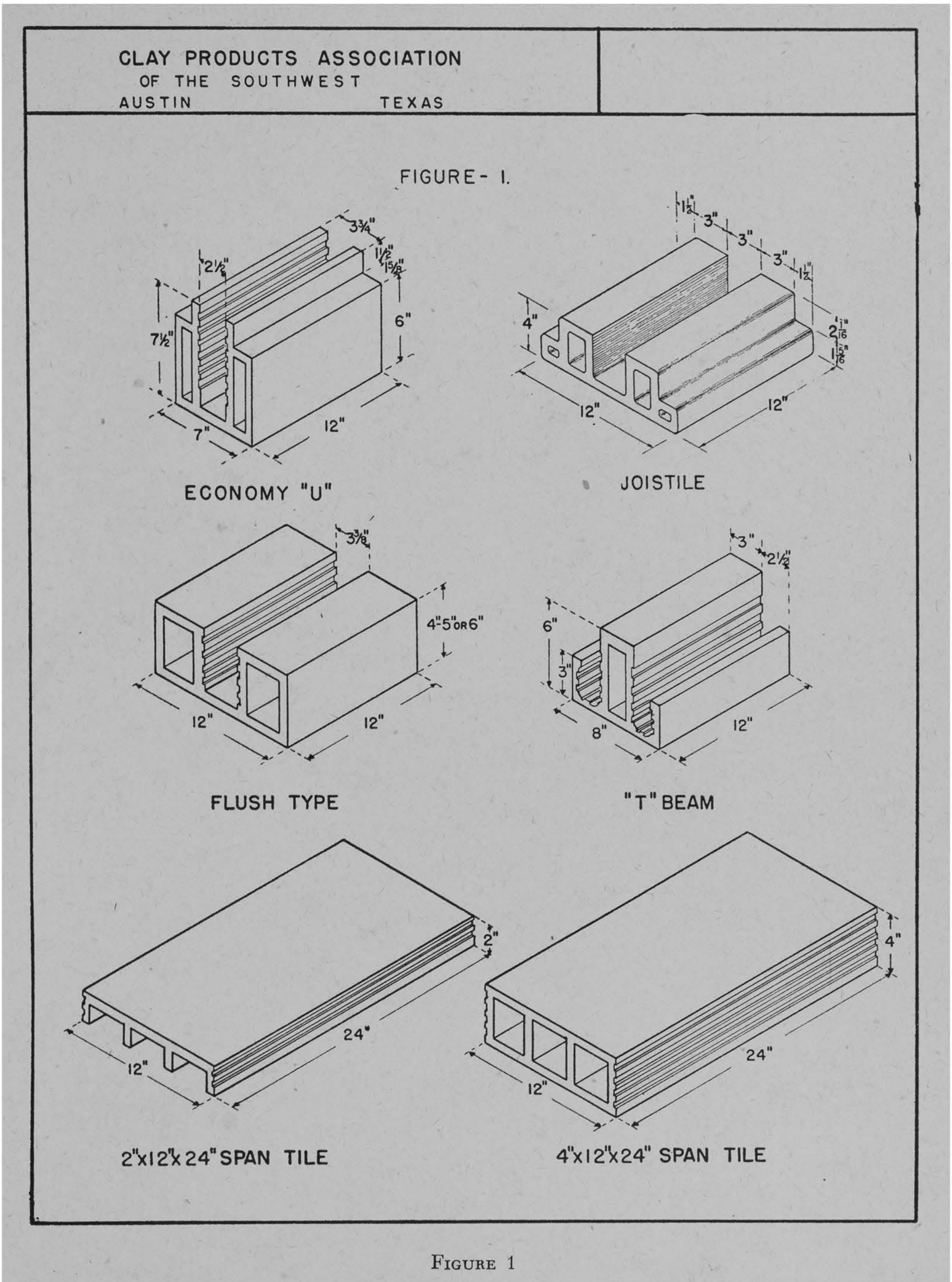

CLAY PRODUCTS ASSOCIATION
OF THE SOUTHWEST
AUSTIN TEXAS
FIGURE- I.
ECONOMY "U"
JOISTILE
FLUSH TYPE
"T" BEAM
2"x12"x24" SPAN TILE
4"x12"x24" SPAN TILE

FIGURE 1

Introduction

One of the most recent developments in the building industry is the use of precast beams made of structural clay tile combined with concrete and reinforced with steel rods, for the construction of masonry floors and roofs. The fact that no centering or form work is necessary, reduces materially the square foot cost of the assembly, and greatly simplifies its erection.

There are a number of designs of "beam tile," the most commonly used being the Economy "U"; the Joistile; the "T" Beam; and the Flush Type beam. These tile are shown in Figure 1, and the dimensions given are standard practice in Texas. The "Spanner tile" used in combination with the beams are also shown, and are usually made in 2″ or 4″ thicknesses. The standard length is 24″, but shorter blocks may be used if excessive floor loads make it necessary to place the beams closer together.

The Economy "U" slab is built in five steps:

(1) Special shaped "beam tile" are laid in a line, end to end, on a firm flat surface. This forms one or more troughs running the length of the row of tile.

(2) The proper amount of reinforcing steel is embedded in sufficient concrete in these troughs, so that at the completion of the curing period it can be handled.

(3) The beams are then placed on their supports, either bearing walls or girders, and spaced in accordance with the framing plans.

(4) The special blocks used for making the beams are so designed that shoulders are formed on the sides of the beams. "Spanner tile" resting on these shoulders fill the open spaces between the beams, making a continuous floor surface.

(5) For the final step, top reinforcing is put in place if the design calls for it, piping and electric conduits are set, and the surface covered with concrete to a proper depth.

In designing a floor of this type, the standard formulae for concrete T-beam construction are used. The strength of the tile in the assembly is not considered in the design, with the exception that the shells of the beam tile adjacent to the concrete are figured in compression and shear, in accordance with the accepted practice in the design of composite tile and concrete slabs.

An important factor to be considered is the action of the beam tile in resisting the diagonal tension stress developed in the beam under load. The tile are assumed to act as a continuous series of stirrups.

There is nothing revolutionary in the design of the beams, and the usual methods for determining the amount of steel reinforcement, shear, and bond stress are employed. The novelty and economy of this type of construction lie in the fact that the prescast beams develop sufficient strength to carry the construction load without extensive form work.

In the use of this type of construction a number of questions have been asked which can only be answered by making strength tests of typical beams. The tests reported herein were made for the purpose of answering some of the questions concerning diagonal tension stresses, buttered joints, etc.

The particular problems studied were:

(1) Resistance of a tile-concrete beam to diagonal tension stresses as compared with a concrete beam.

(2) The extent the outside shell helps in carrying the diagonal tension stresses.

(3) Relation between the observed and calculated diagonal tension stresses.

(4) Depth of precast concrete required to give sufficient bond between concrete and tile to prevent a horizontal shear failure at the precasting plane.

(5) The necessity of buttered joints, that is, placing mortar between ends of tile before placing concrete in the channels.

(6) Whether weakness results from the fact that joints between tile are not staggered as now required in Section 817(c) of the Report of Joint Committee on Standard Specifications for Concrete and Reinforced Concrete.

Physical Properties of Materials Used

Tile

The tile used in these tests were Economy "U" tile furnished by the Clay Products Association of the Southwest, and were manufactured from a buff burning fire clay. The tile section is shown in Figure 1, and the detail test description, data, and results are presented in the Appendix.

The compressive strength of the tile was determined by capping both ends of the tile with plaster of paris to obtain a smooth bearing surface and applying a compressive load to the ends. Compressive strength, determined by dividing the meximum load carried by the net cross-sectional area, was found to be about 8,300 pounds per square inch.

The modulus of elasticity of the tile in compression was determined by using electric strain gages attached at the center of a tile, and an average value was found to be 3,600,000 pounds per square inch.

The tensile strength and modulus of elasticity in tension of the tile were determined from specimens cut out of the tile in the form of a standard mortar briquet with an elongated center section to enable the attaching of electric strain gages. The tile briquets were tested in an ASTM standard briquet-testing machine. The average tensile strength of the tile cut parallel to the axis of the tile was 780 pounds pere square inch. The average tensile strength of the tile cut perpendicular to the axis of the tile was found to be 650 pounds per square inch. The modulus of elasticity of the tile was determined by using electric strain gages attached to opposite sides of a tile briquet. An average value was found to be 3,700,000 pounds per square inch.

Several different kinds of tests to determine the bond strength of the concrete to the tile were tried before a reasonably satisfactory method was found. A tile was poured full of concrete of the same properties as was used in the beams and after curing was cut into sections that were 2″, 4″, 6″, and 10″ in length. In the longer specimen, bending stresses were introduced causing failure by bending rather than bond. A curve of average bond stress at failure versus length of section tested indicated a bond strength of approximately 380 pounds per square inch.

The average absorption of the tile determined by the procedure specified for structural clay tile by ASTM, Designation C112-36, was found to be 5.66 per cent.

Concrete

The concrete used had a cement factor of 5 sacks per cubic yard and a water-cement ratio of 7.27 gallons per sack of cement. The optimum fine aggregate content was found to be 29 per cent by absolute volume.

The aggregates used were from Colorado River sources. The coarse aggregate passed a ¾″ sieve. The fine aggregate used passed a ¼″ mesh sieve. The cement used in all the concrete was Alamo Red Bag, high-early strength cement. High-early strength cement was used to permit early handling of the beam. The aggregates, cement, and water were weighed on scales to the nearest 0.1 pound. After mixing the aggregates and cement dry and then adding the water, the mass was mixed with shovels until a uniform mixture was obtained. Two ASTM standard cylinders were made from each batch of concrete. Standard slump tests were made. The slumps varied from 5 inches to 8½ inches.

The cylinders from the batches used in pouring the precast cancrete were tested at 30 days while those used in pouring the slabs were tested at 28 days. The compressive strength of the cylinders except for one batch varied from 3,000 pounds per square inch to 3,600 pounds per square inch with an average of approximately 3,300 pounds per square inch.

Reinforcing Steel

The steel used was one inch square deformed bars of the intermediate grade billet steel. Tension tests on the steel gave an average yield point of 51,600 pounds per square inch, an average tensile strength of 84,800 pounds per square inch, and an average elongation in 8 inches of 22 per cent.

Design of Beams

The beams were designed to provide for the failure to occur in diagonal tension by doing the following:

(1) Using a relatively short span.
(2) Providing sufficient steel to prevent failure in tension.
(3) Providing a slab of sufficient area to prevent failure in compression.
(4) Providing anchorage for the steel to prevent failure in bond.

In the calculation of the stresses in the beams, the following formulas were used:

$$k = \frac{np + \frac{1}{2}(t/d)^2}{np + t/d}$$

$$z = \frac{3kd - 2t}{2kd - t} \times \frac{t}{3}$$

$$jd = d - z$$

$$f_c = \frac{M}{\left(1 - \frac{t}{2kd}\right) btjd}$$

$$f_s = \frac{M}{A_s jd}$$

$$v = \frac{V}{\frac{7}{8} b'd}$$

$$u = \frac{V}{\Sigma_o \frac{7}{8} d}$$

where:

$$n = \frac{E_s}{E_c}$$

$$p = \frac{A_s}{bd}$$

t = thickness of slab.
d = effective depth of beam.
kd = depth from top of slab to neutral axis.
z = depth from top of slab to center of gravity of compression.

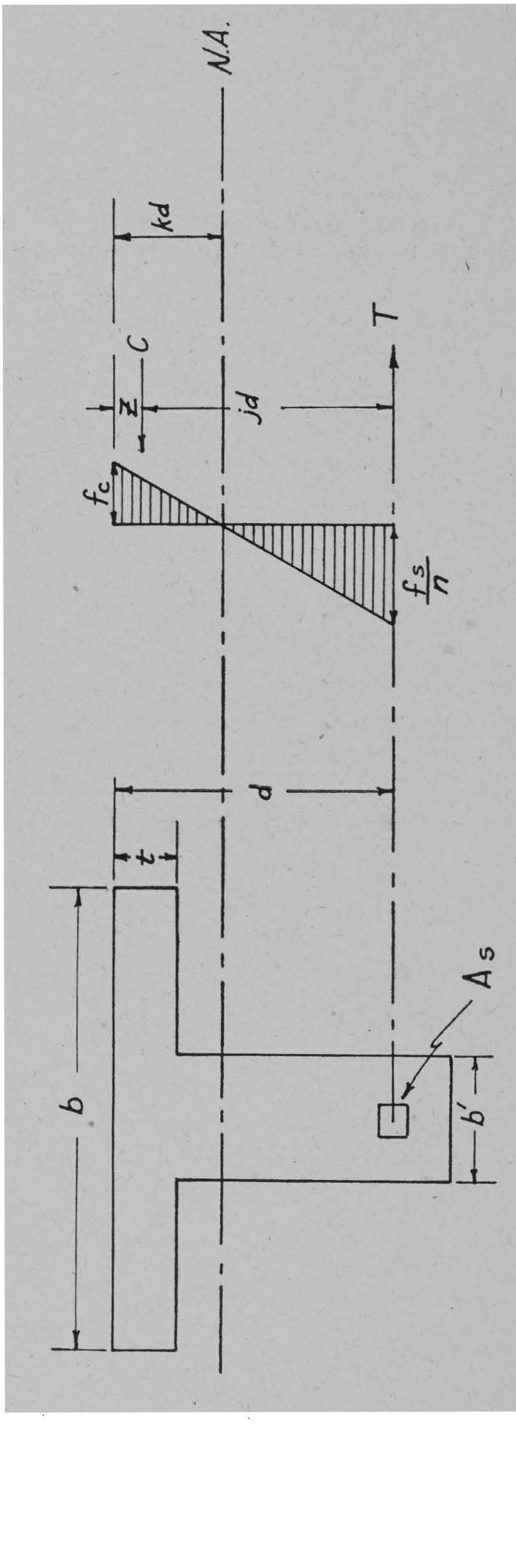


FIGURE 2

jd = length of moment arm between compression area and steel.
M = moment due to load applied.
f_c = compressive stress in the concrete.
f_s = tensile stress in steel.
v = calculated shear stress.
u = calculated bond stress.
V = total shear.
Σo = perimeter of reinforcing bars.
b = width of slab.
b′ = width of stem.

The beams were designed as though they were ordinary reinforced concrete T-beams with a stem width equal to the width of the channel plus the thickness of the inner shells of the tile as shown in Figure 2.

The seven-foot span was selected as the most desirable. The slab thickness was selected to be 2 inches and the slab width, to insure placing in the testing machine, was selected to be 16 inches. The total depth determined by the spanner tile turned down and with a 2-inch topping was 10½ inches. The effective depth was 8¾ inches.

Assuming a failing shear stress of 200 pounds per square inch and third point loading, the calculated maximum load was estimated to be 11,500 pounds. With an allowable stress of 20,000 pounds per square inch on the steel, it was found that a one-inch square bar was needed to assure a failure in shear. The deformed bar was selected to give better bond strength.

Allowable live load by conventional reinforced concrete design:

$$\frac{t}{d} = \frac{2}{8.75} = 0.228$$

$$p = \frac{1}{16 \times 8.75} = 0.00715$$

$$n = 10$$

$$k = \frac{0.0715 + \frac{1}{2}(0.228)^2}{0.0715 + 0.228} = \frac{0.0975}{0.2995}$$

$$k = 0.325$$

$$kd = 2.84 \text{ inches.}$$

$$z = \frac{3 \times 2.84 - 2(2)}{2 \times 2.84 - 2} \times \frac{2}{3} = \frac{4.52}{3.68} \times \frac{2}{3}$$

$$z = 0.82 \text{ inches.}$$

$$jd = 8.75 - 0.82 = 7.93 \text{ inches.}$$

Design for shear:

Allowable $v = 0.03\ f'c$

Allowable $v = 0.03 \times 3{,}000 = 90$ pounds per square inch.

Allowable $V = v \dfrac{7}{8} b'd$

Allowable $V = 90 \times \dfrac{7}{8} \times 8.75 \times 3.75 = 2{,}580$ pounds.

Dead Load $V = \dfrac{7 \times 75}{2} = 260$ pounds.

Allowable Live Load $V = 2{,}320$ pounds.

Allowable Live Load for Shear $= 4{,}640$ pounds.

Design for moment:

$M = f_s\ A_s\ jd.$

Allowable $M = 20{,}000 \times 1 \times 7.93 = 158{,}600$ inch pounds.

$$\text{Dead Load } M = \frac{75\ (84)^2}{8} = 5{,}500 \text{ inch pounds.}$$

Allowable Live Load $M = 153{,}000$ inch pounds.

Allowable Live Load for moment $= \dfrac{153{,}100 \times 2}{28} = 10{,}940$ pounds.

Design for bond:

Allowable $u = 0.05\ f'_c \times 1.5$

Allowable $u = 0.05 \times 3{,}000 \times 1.5 = 225$ pounds per square inch.

Allowable $V = u \dfrac{7}{8} b\Sigma o$

$$\text{Allowable } V = 225 \times 4 \times \frac{7}{8} \times 8.75 = 6{,}900 \text{ pounds.}$$

Dead load $V = 260$ pounds.

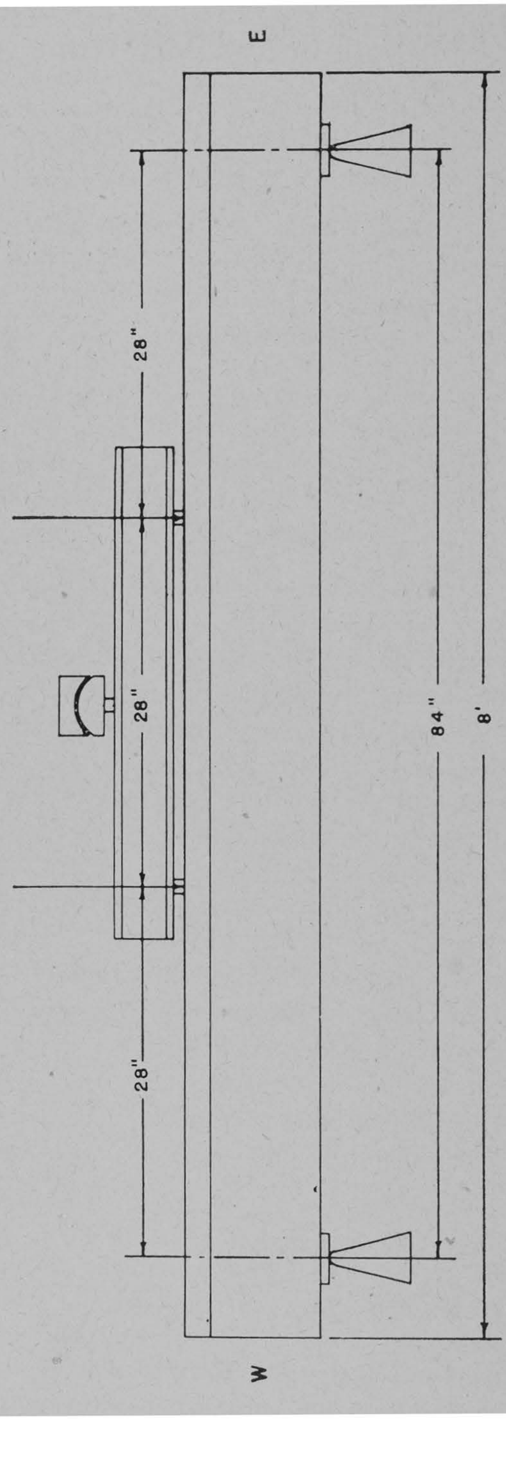
Allowable Live Load for Bond $= 13{,}280$ pounds.

Thus allowable live load on beam would be limited to 4,640 pounds by the shear stress.

Method of Loading

The loads were applied to the beams at the third points as shown in Figure 3. The beams were placed in a 400,000-pound capacity Tinius Olsen Universal testing machine and the loads applied by a spherically seated bearing block through a ¾-inch square bar resting on a 6-inch W.F. steel beam. The steel beam rested on ¾-inch square bars embedded in plaster of paris at the third points of the beam. The supports were steel plates 3½ inches wide resting on curved bases.

One test was made with the support on rollers, permitting the ends to be free; the method most used tended to restrain the movement of the ends. Because of the weight of the beams it was difficult to place the supports on rollers and then put the beams on the supports, therefore, the loads were applied without the supports being free to move. As expected, other irregularities of the beam prevented the detection of any variation due to the difference in the type of support.



LOADING DIAGRAM

FIGURE 3

Comparison of Concrete Beams with Concrete-Tile Beams

Purpose

Four beams were constructed and tested in this series to make a comparison between the shear strength of the tile-concrete beams and the concrete beams. Two were constructed using the Economy "U" tile as forms for the stems and two were constructed using timber forms. The stem width of the concrete beams was equal to that of concrete-tile beams including the inner shells of the tile.

The forms used in pouring the beams of this series and the cross-section of the beams after pouring are shown in Figures 4, 5, and 6.

Method of Construction

The beams of this series were poured without precast concrete in the tile beams so as to have the two types as much alike as possible. About one inch of concrete was placed in the bottom of the forms and the reinforcing bar worked into the concrete until the anchors rested on the bottom of the forms. The stem part of the form was then filled with concrete and rodded well with bullet-pointed rods. Then the slab was poured full and rodded well, after which the top was tamped and finished. The beams and cylinders were cured with moist cement sacks for seven days and remained dry for the remainder of 28 days.

Results

All beams failed in diagonal tension. Some of these failures are shown in Figure 7. The average load carried by the concrete-tile beams was 16,300 pounds as compared to the average load carried by the concrete beams of 11,630 pounds. The concrete cylinders made with the concrete-tile beams tested an average strength of 3,300 pounds per square inch as compared to 3,400 pounds per square inch for the cylinders made with the concrete beams.

The results of this series of tests indicated conclusively that the tile carried a considerable amount of the shear stresses induced in the tile-concrete beams. The shear performance as given in Table 1, indicated that a calculated shear stress at failure of about 38 per cent more for the tile-concrete beams than for the concrete beams. It is possible that some portion of this greater strength is due to the curing of concrete in tile forms.

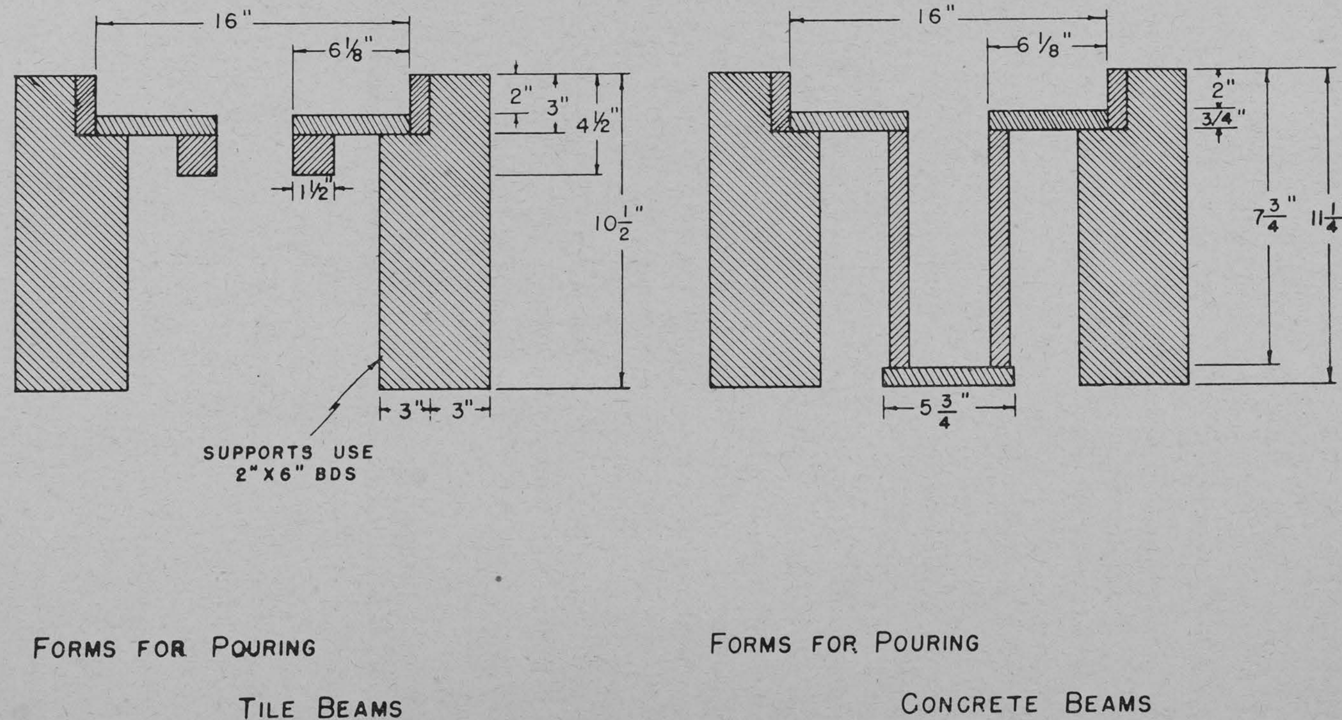

16"
6 1/8"
2"
3"
4 1/2"
1 1/2"
10 1/2"
3"
3"
SUPPORTS USE
2"X6" BDS
FORMS FOR POURING
TILE BEAMS
16"
6 1/8"
2"
3/4"
7 3/4"
11 1/4"
5 3/4"
FORMS FOR POURING
CONCRETE BEAMS

FIGURE 4

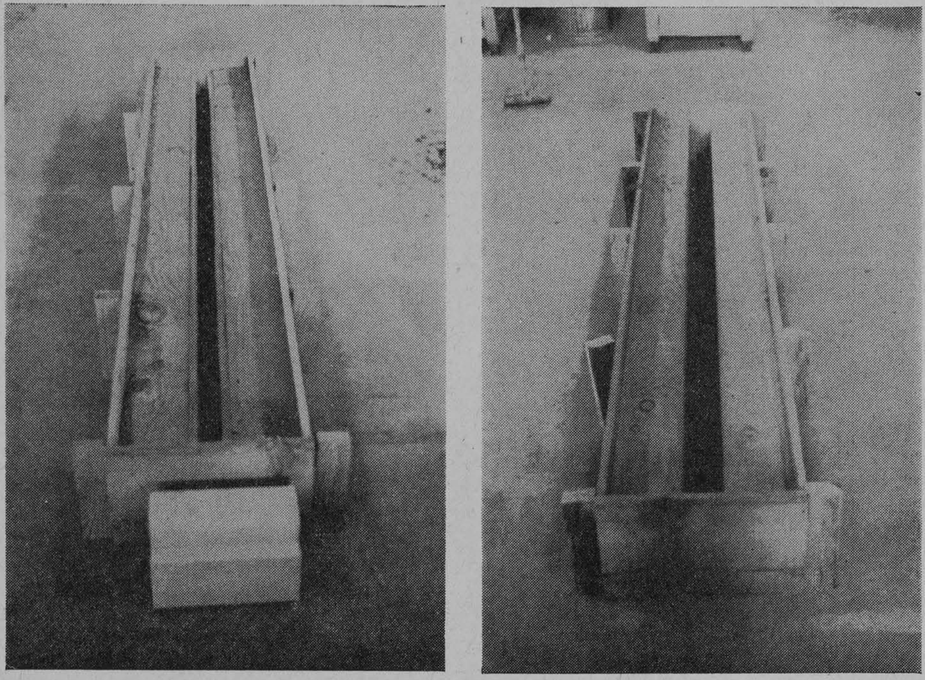
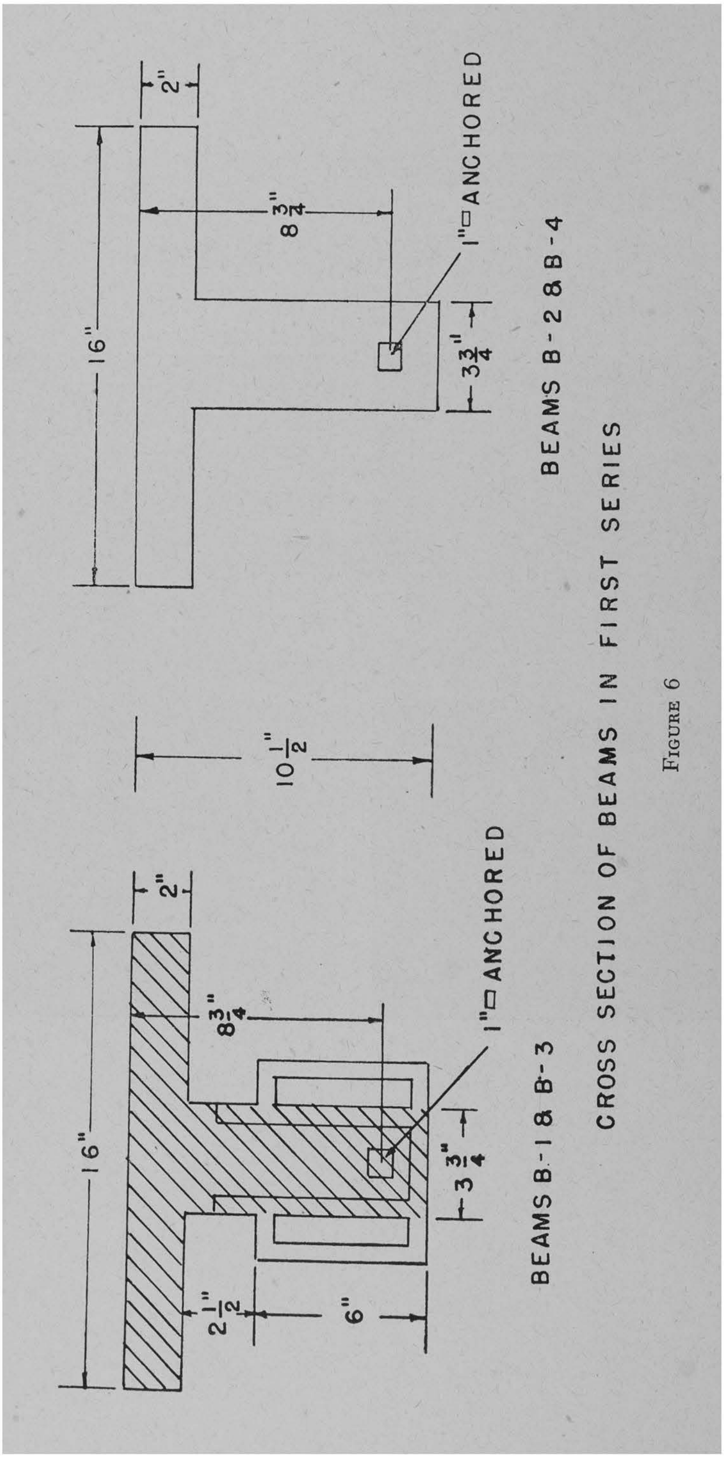


FIGURE 5



CROSS SECTION OF BEAMS IN FIRST SERIES

FIGURE 6

FIGURE 7

This series of tests leaves no doubt concerning the strengthening of this type of beam by the presence of this particular tile. It must be realized that the tile used in these tests have a high tensile strength (a strength greater than concrete).

Figure 8 shows the live load-deflection curves for the beams of this series. It is evident from these curves that the difference in the deflection of the concrete beam and the tile-concrete beam is not significant, but it does appear that the tile adds a little to the stiffness of the beam.

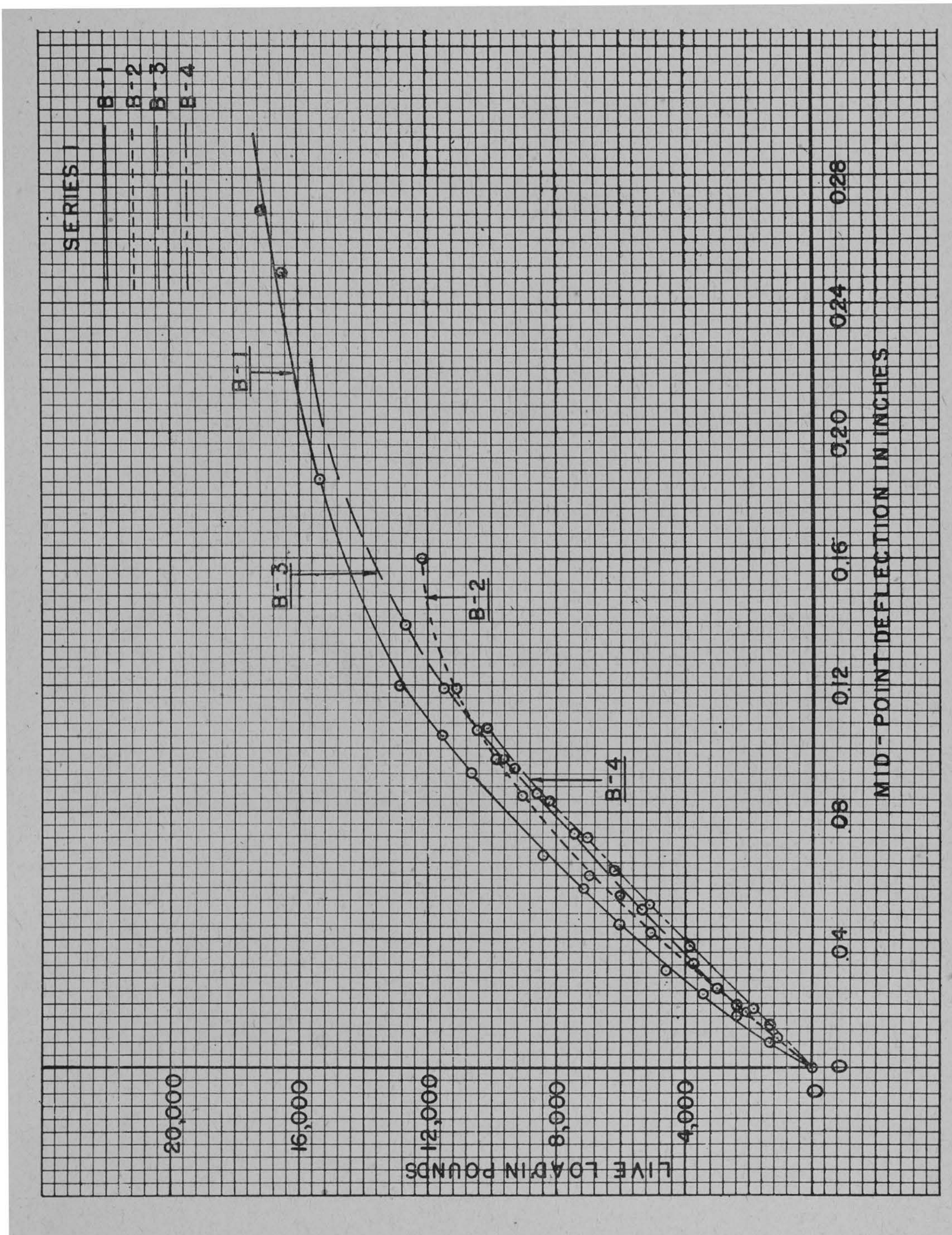
It was observed in these tests that the concrete beams failed completely without any previous indication of rupture. The tile-concrete beams, however, developed visible cracks prior to the ultimate load. Tile-concrete beam B-1 cracked noticeably at a load of 15,170 pounds and subsequently failed at 16,900 pounds. Tile-concrete beam B-3 cracked noticeably at a load of 12,700 pounds and subsequently failed at 15,700 pounds. This was true of all except one of the tile-concrete beams tested in the first and second series. Sometimes these initial cracks appeared on one end of the beam and final rupture occurred on the opposite end.

TABLE I

Data on Comparison of Tile-Concrete Beams with Concrete Beams

Beam		Design Load* (Lbs./Ft.)	Loads at Failure				Calculated Shear Stress at Failure (Lbs./in.^{2})	Type of Failure
			Live		Dead	Total		
No.	Type		Total at Third Pts. (Lbs.)	Equiv. Uniform† (Lbs./Ft.)	(Lbs./Ft.)	(Lbs./Ft.)		
B-1	Tile concrete	737	16,900	2,415	75	2,490	302	Dia. Ten.
B-2	Concrete	737	12,130	1,735	75	1,810	221	Dia. Ten.
B-3	Tile-concrete	737	15,700	2,245	75	2,320	283	Dia. Ten.
B-4	Concrete	737	11,130	1,590	75	1,665	204	Dia. Ten.

*Design load based on an allowable shear stress of 90 pounds per square inch.
†Calculated equivalent uniform live load for shear.



SERIES I
B-1
B-2
B-3
B-4
LIVE LOAD IN POUNDS
20,000
16,000
12,000
8,000
4,000
0
MID-POINT DEFLECTION IN INCHES
0
.04
.08
0.12
0.16
0.20
0.24
0.28

FIGURE 8

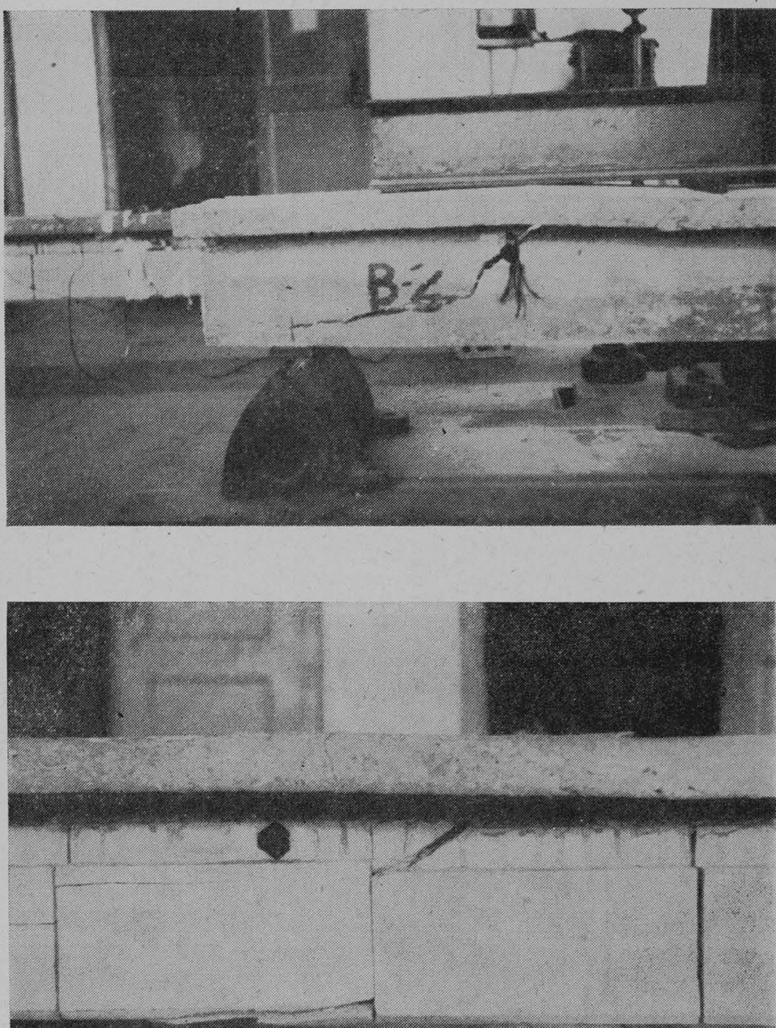


FIGURE 9

Figure 9 shows a typical diagonal tension failure for a concrete beam and for a tile-concrete beam. Figure 10 shows the appearance of the tile before the outside shell is removed and after the outside shell is removed. All tile-concrete beams that failed in diagonal tension developed similar rupture planes.

Section 817(c) of the Specifications from the *Report of the Joint Committee on Standard Specifications for Concrete* stipulates:

> "In ribbed tile construction where fillers are used consisting of burned clay, or concrete tile having a net compressive strength in the shells at least equal to that of the concrete in the ribs, and so placed that the joints in alternate rows are staggered, the shells of the fillers in contact with the ribs may be used in computing the shearing stress at any section of the rib."

The results of these tests indicate definitely that there is no need for staggered tile joints. That tile-concrete beams withstood greater loads than equivalent concrete beams even though both failed in diagonal tension seems to be adequate verification of this fact. It is further noted that the plane of rupture was not appreciably affected by the presence of a vertical joint. Figure 10 shows beam B-3 which was a typical failure. The plane of rupture is virtually straight across the joint.

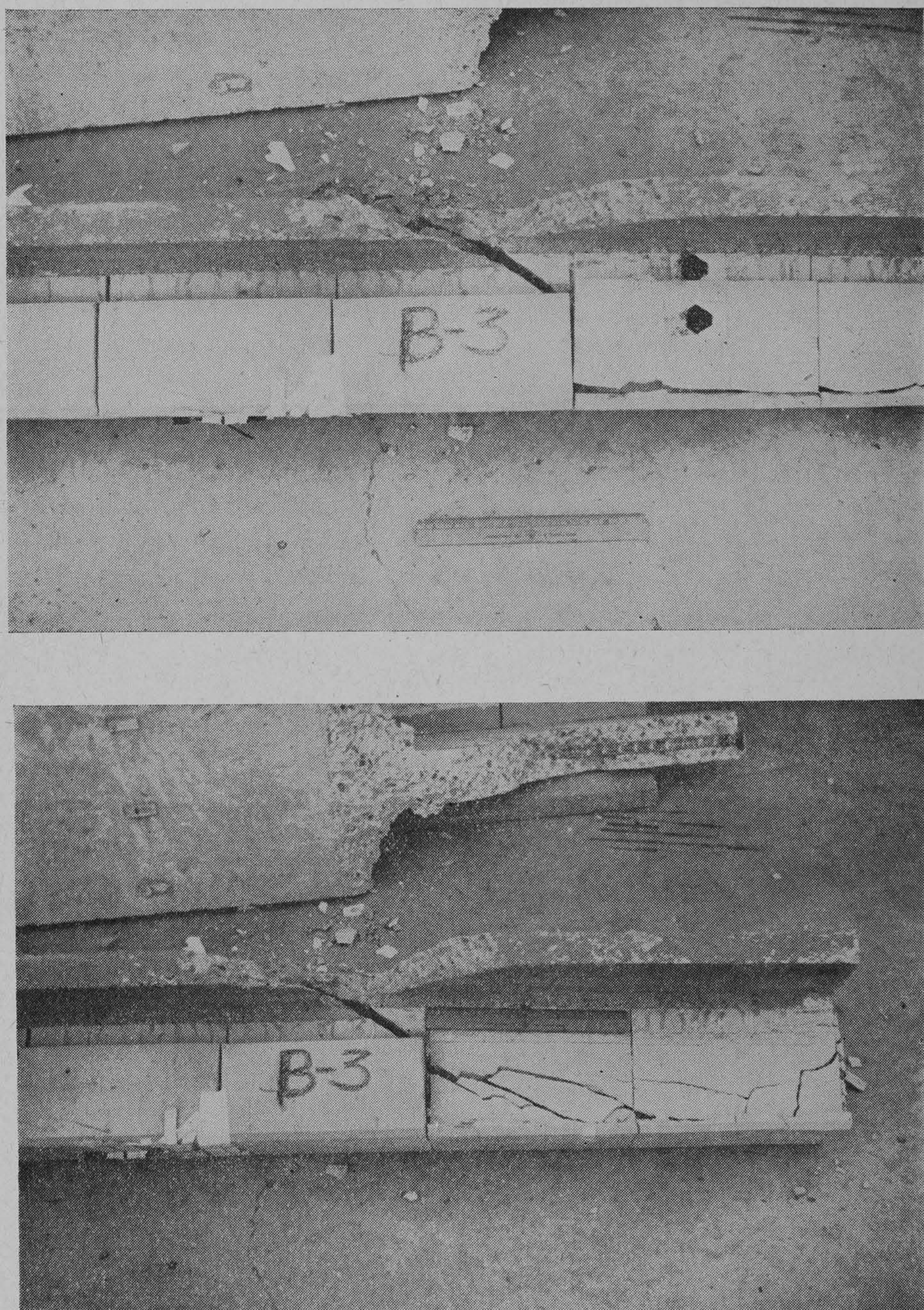


FIGURE 10

Depth of Precasting

Purpose

Since one of the purposes of this type of construction is to use the precast beams to support the floor slab while it is being poured, this series of tests was performed to determine the maximum depth of precasting. The depth of precasting is determined mainly by the particular construction problem. The necessary tile surface to develop adequate bond between the floor slab and the precast unit was studied in this group of tests.

Method of Construction

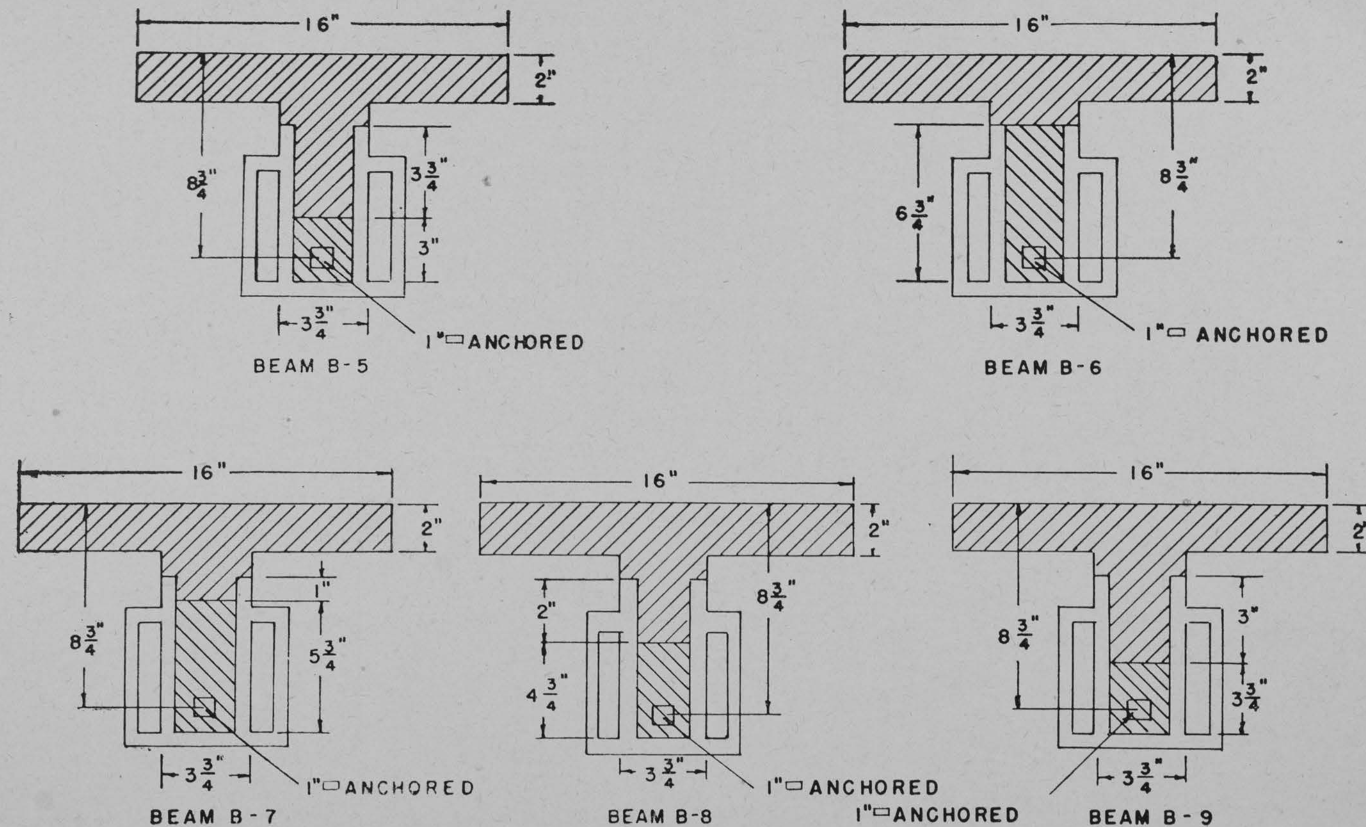
The minimum depth of precasting was 3″ and the maximum was 6¾″. The latter was to the top of the tile. The same forms used in pouring the tile-concrete beams of the first series were used to construct five beams of this series. The cross-sections of the beams tested are shown in Figure 11.

After arranging the tile along a straight line, concrete was poured to a depth of about one inch and the steel worked into place. The concrete was then poured to the desired depth of precasting and rodded well. The top was vibrated with the end of a 2″ x 4″ board until a smooth surface was obtained. After the precast unit had cured for 2 days, the floor slab was poured. The beams were then cured for 7 more days with moist cement sacks and allowed to stand dry an additional 21 days.

Results

The load results for this series of tests are given in Table II. All the beams in this series failed in diagonal tension except for No. B-6 which failed in compression of the concrete at the top of the tile. In effect this beam acted under test as though it were a beam of a section equivalent to the tile section with a separate floor slab lying on top. The other beams performed the same as the tile-concrete beams of the previous series. This indicates that the bond between the tile and concrete is sufficiently strong when a beam is precast to a depth of 5¾ inches. In other words, in order to transfer the horizontal shear stresses from the floor slab to the web, one inch of tile is needed to develop adequate bond (as indicated by laboratory tests).

Figure 12 shows the live load-deflection curves for the beams of this series. The deflections of this series of beams, with the exception of B-6, correspond very closely to those of the previous series indicating that the precasting of the beams does not reduce the stiffness. The deflection of



CROSS SECTIONS OF BEAMS IN SECOND SERIES

FIGURE 11

beam B-6 was considerably greater than that of the other beams of this series. This was due to the fact that the slab did not act as an integral part of the beam.

The writers consider this part of the investigation as one of the most important phases of this study. Several construction jobs have been examined in which the tile-concrete beams had been precast to the top of the tile as shown in Figure 13. This series of tests definitely shows the danger of such practice. At least one inch of tile should be left at the top to permit the development of adequate bond between the floor slab and the precast unit. This applies only to the economy "U" type tile and not the flush type tile. Tests made on the flush type tile indicated that they could be precast to the top.

TABLE II

Data on Effect of Depth of Precasting on Strength of Beams

No.	Depth of Precasting	Design* (Lbs./Ft.)	Loads at Failure: Live: Total at Third Pts. (Lbs.)	Loads at Failure: Live: Equiv. Uniform.† (Lbs./Ft.)	Loads at Failure: Dead (Lbs./Ft.)	Loads at Failure: Total (Lbs./Ft.)	Calculated Shear Stress at failure (Lbs./in.²)	Type of Failure
B-5	3"	737	16,300	2,340	75	2,415	295	Dia. Ten.
B-6	6¾"	737	10,260	1,465	75	1,540	188	Comp. at top of pre-casting
B-7	5¾"	737	17,450	2,490	75	2,565	313	Dia. Ten.
B-8	4¾"	737	16,000	2,285	75	2,360	288	Dia. Ten.
B-9	3¾"	737	15,800	2,260	75	2,335	285	Dia. Ten.

*Design load based on an allowable shear stress of 90 pounds per square inch.
†Calculated equivalent uniform live load for shear.

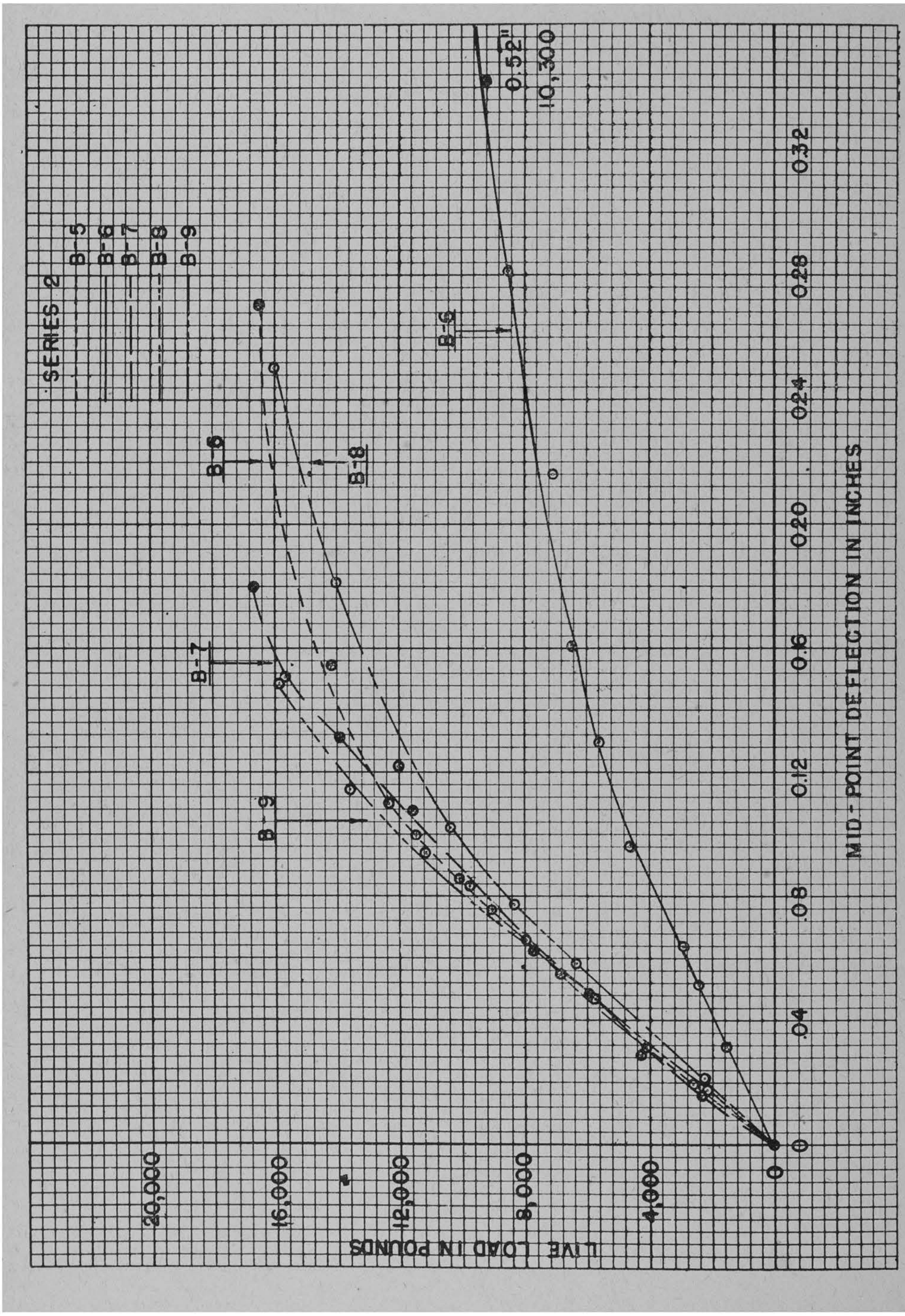

SERIES 2
B-5
B-6
B-7
B-8
B-9
0.52"
10,300
20,000
16,000
12,000
8,000
4,000
0
LIVE LOAD IN POUNDS
MID-POINT DEFLECTION IN INCHES
0.12
0.20
0.24
0.28
0.32

FIGURE 12

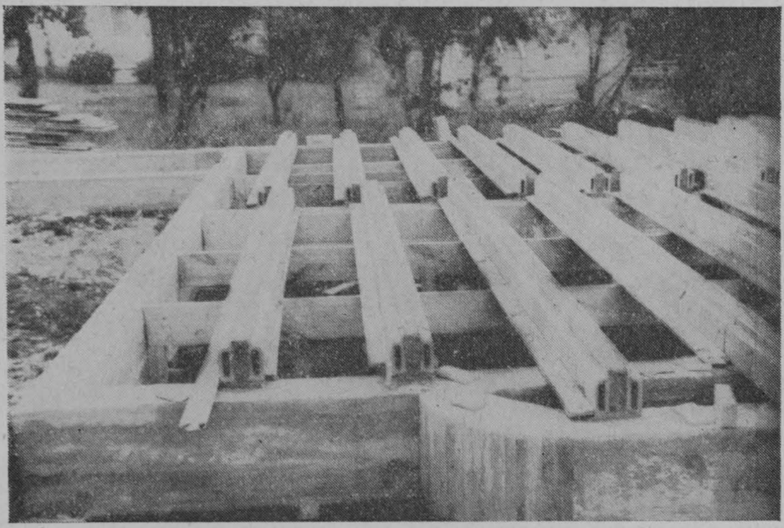


FIGURE 13

Influence of Buttered and Non-Buttered Joints on Strength of Beam

Purpose

Since placing mortar between the ends of the tile before precasting is an expensive item, this series of tests was performed to determine whether or not the buttering of the tile joints made any difference in the shear strength of the beams.

Method of Construction

Tile for four beams were laid with the joints buttered. After the mortar had cured sufficiently, the beams were precast to a depth of about 5¼″ and the topping poured as in the previous series.

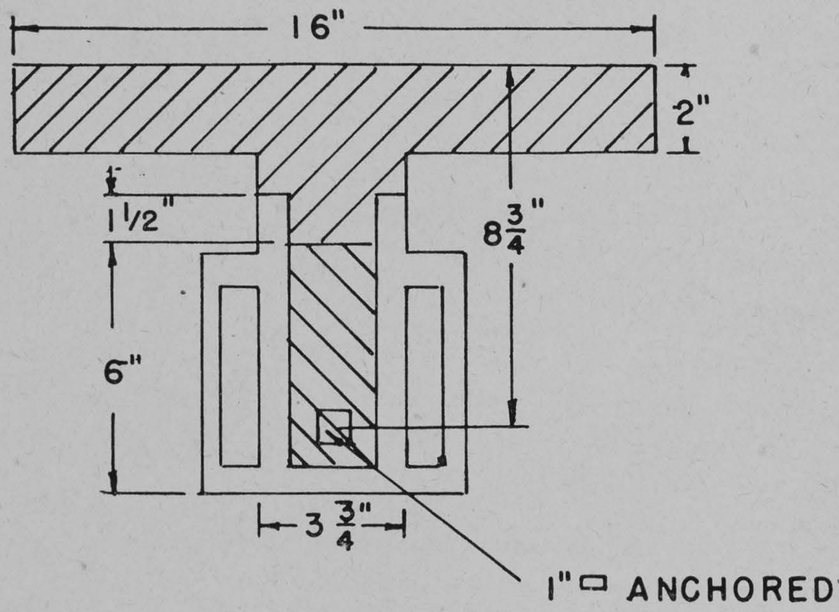
Results

The maximum loads carried by the beams of this series varied appreciably more than the ones of the same type of construction of the other series.

The average load carried by beams B-5, B-7, B-8, and B-9 of the previous series was 16,390 pounds as compared to an average of 15,900 pounds for beams C-1, C-2, and C-4 of this series. This seems to definitely indicate that the buttering of the tile joints makes no difference in the shear strength of the beams. In fact, the mortar was knocked loose in one joint of beam C-1 and the failure occurred on the opposite end of the beam as shown in Figure 15.

Figure 16 shows the live load-deflection curves for the beams of this series. The deflection of these beams corresponded very closely to the deflection of the beams of the two previous series, indicating that the buttering of the tile joints does not add to the stiffness of the beams.

It was noted in this series that no initial cracking occurred prior to final rupture as happened in the first and second series. The tile-concrete beams failed abruptly—similar to the concrete beams.



CROSS SECTION OF BEAMS IN THIRD SERIES

FIGURE 14

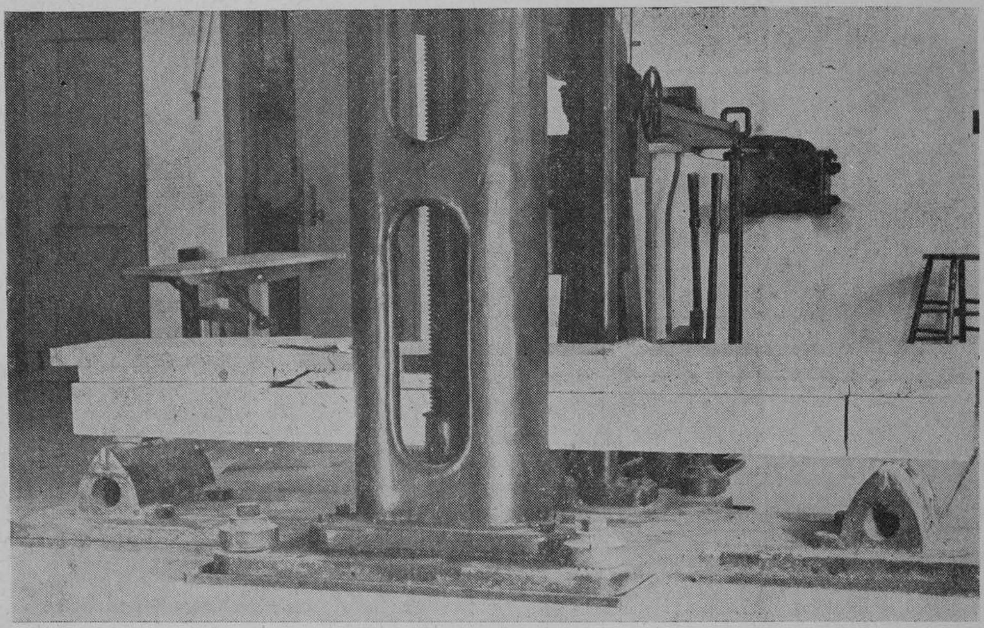


FIGURE 15

TABLE III

Data on Tests of Beams with Buttered Joints

Beam No.	Design Load* (Lbs./Ft.)	Loads at Failure				Calculated Shear Stress at Failure (Lbs./in.^{2})	Type of Failure
		Live		Dead	Total		
		Total at Third Pts. (Lbs.)	Equiv. Uniform† (Lbs./Ft.)	(Lbs./Ft.)	(Lbs./Ft.)		
C-1	737	15,860	2,265	75	2,340	286	Dia. Ten.
C-2	737	17,030	2,435	75	2,510	313	Dia. Ten.
C-3	737	12,990	1,860	75	1,935	236	Dia. Ten.
C-4	737	14,810	2,120	75	2,195	268	Dia. Ten.

*Design load based on an allowable shear stress of 90 pounds per square inch.
†Calculated equivalent uniform live load for shear.

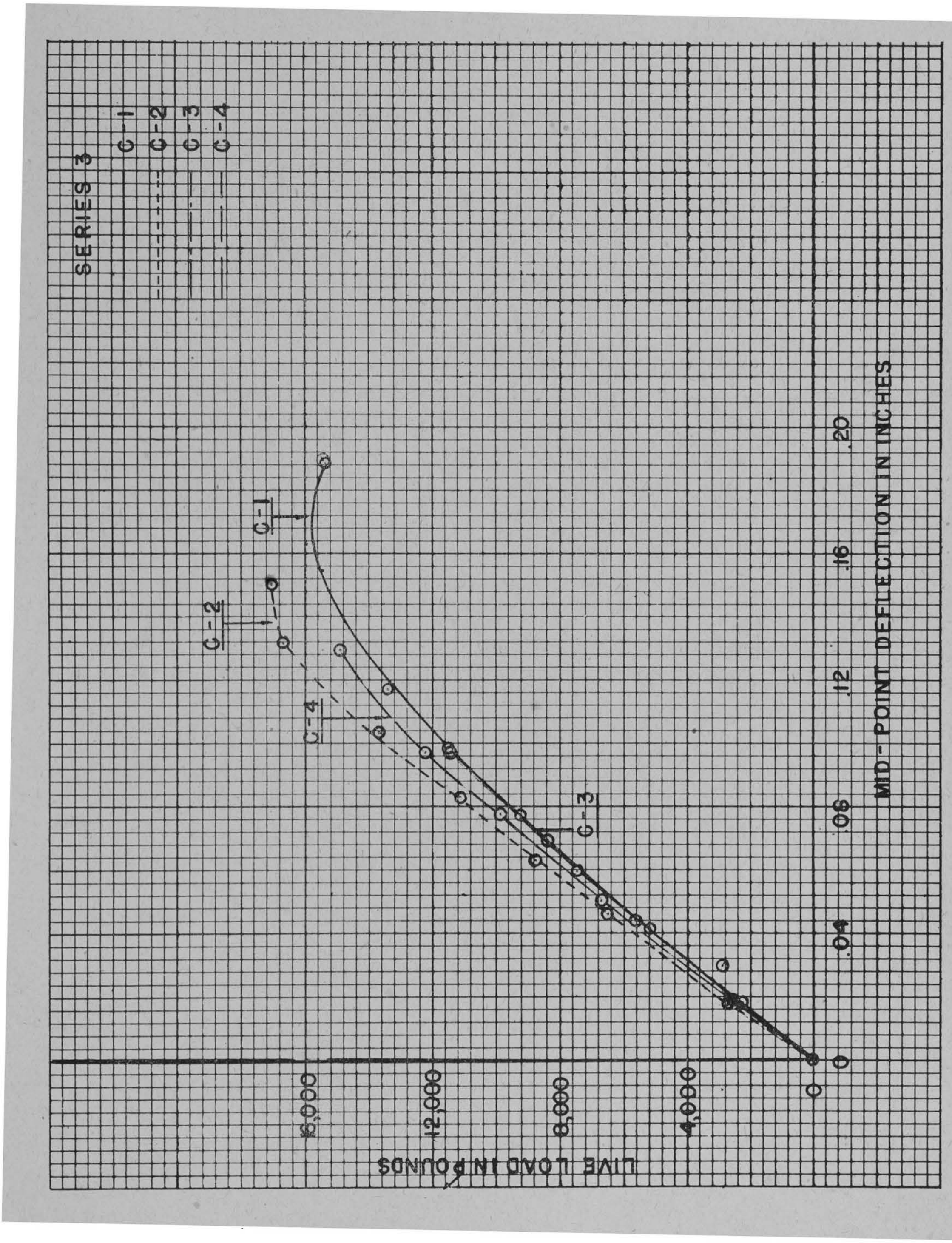

SERIES 3
C-1
C-2
C-3
C-4
LIVE LOAD IN POUNDS
0
4,000
8,000
12,000
16,000
MID-POINT DEFLECTION IN INCHES
0
.04
.08
.12
.16
.20

FIGURE 16

Shear Stress Measurements

Shear stress measurements were made on all the beams tested except B-6. These measurements were made by placing SR-4 type AR-1 electric strain gage rosettes with 13/16-inch gage lengths on the beams as indicated in the beam loading diagrams in Appendix II.

Strain readings in the three directions of the rosettes and corresponding load readings were taken as long as it was possible before the beams ruptured. These strain readings verus the corresponding live load readings were plotted as shown in the rosette load-strain diagram in Figure 17. Where the average strain from two or more rosettes were observed, the average was obtained by averaging the strain in correponding gages of the rosettes. The diagonal tension stress reported was calculated from the average strains.

The calculation of tension, compression, and shear stresses can be made if the strain in any three directions is known by use of the Mohr circle of strains. The magnitude and direction of the principal stresses (tension and compression) can be determined. The maximum shear stress is the average of the maximum tension and compression stresses. The observed shearing stresses reported in the beam test reports of Appendix II were calculated by this method using the average rosette strains. In these calculations Poisson's ratio was assumed to be 0.15 for both the tile and the concrete.

Calculations for a typical problem using the Mohr circle analysis are shown in Figure 18.

One of the problems of this investigation was the relation between the observed and calculated diagonal tension stresses. The accepted calculated shearing stress, more correctly termed diagonal tension stress, has been taken as

$$v = \frac{V}{\frac{7}{8} b'd}$$

Where V is the vertical shear on section, b' is the web width, and d the effective depth. The following table gives the observed shearing stress for each beam under a load of 7,900 pounds. The strain rosettes used to make this observation were located at approximately the neutral axis midway between the support and the third point load.

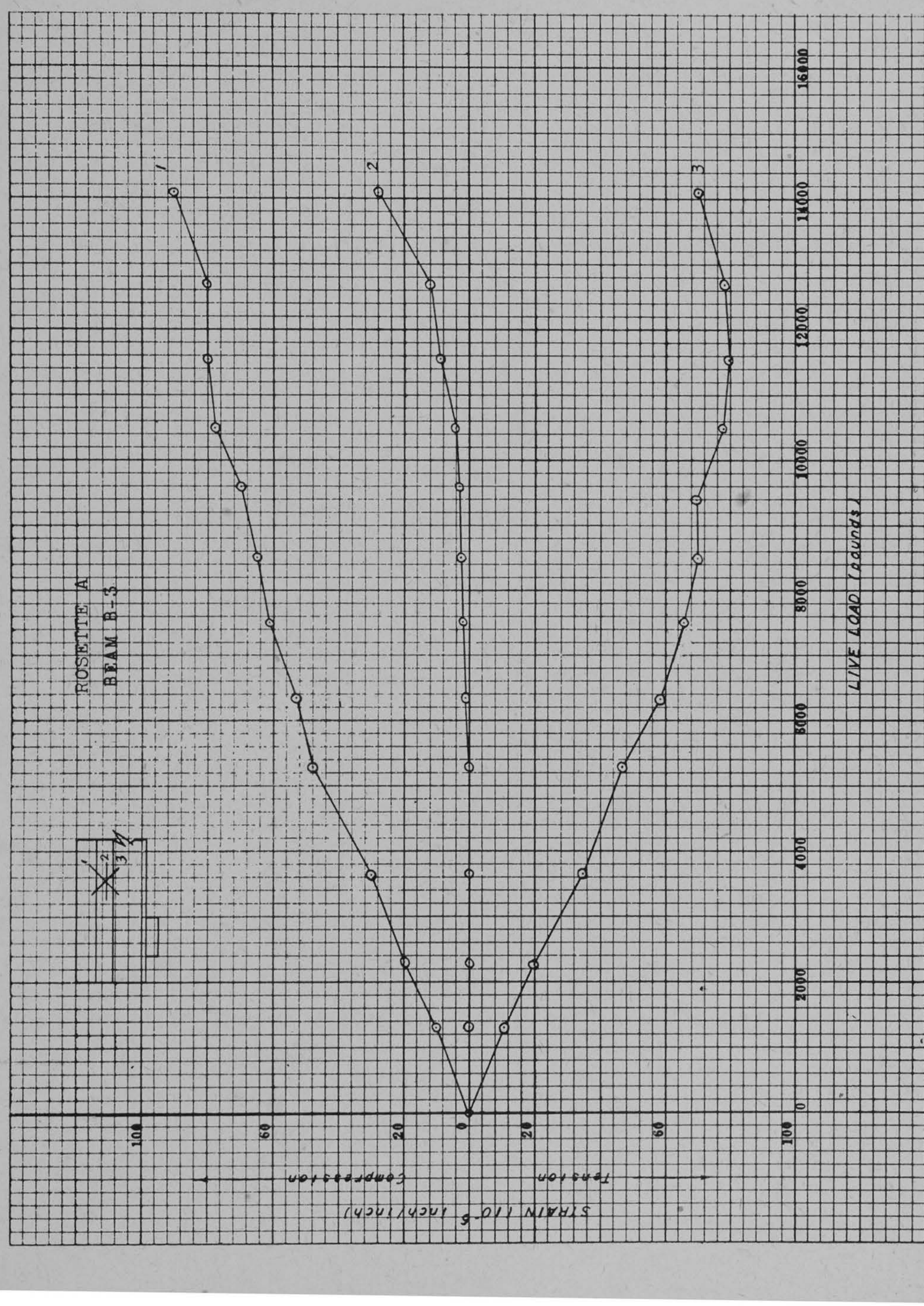

ROSETTE A
BEAM B-3
LIVE LOAD (pounds)
STRAIN (10^-6 inch/inch)
Compression
Tension
0
2000
4000
6000
8000
10000
12000
14000
16000
100
60
20
0
20
60
100
1
2
3

FIGURE 17

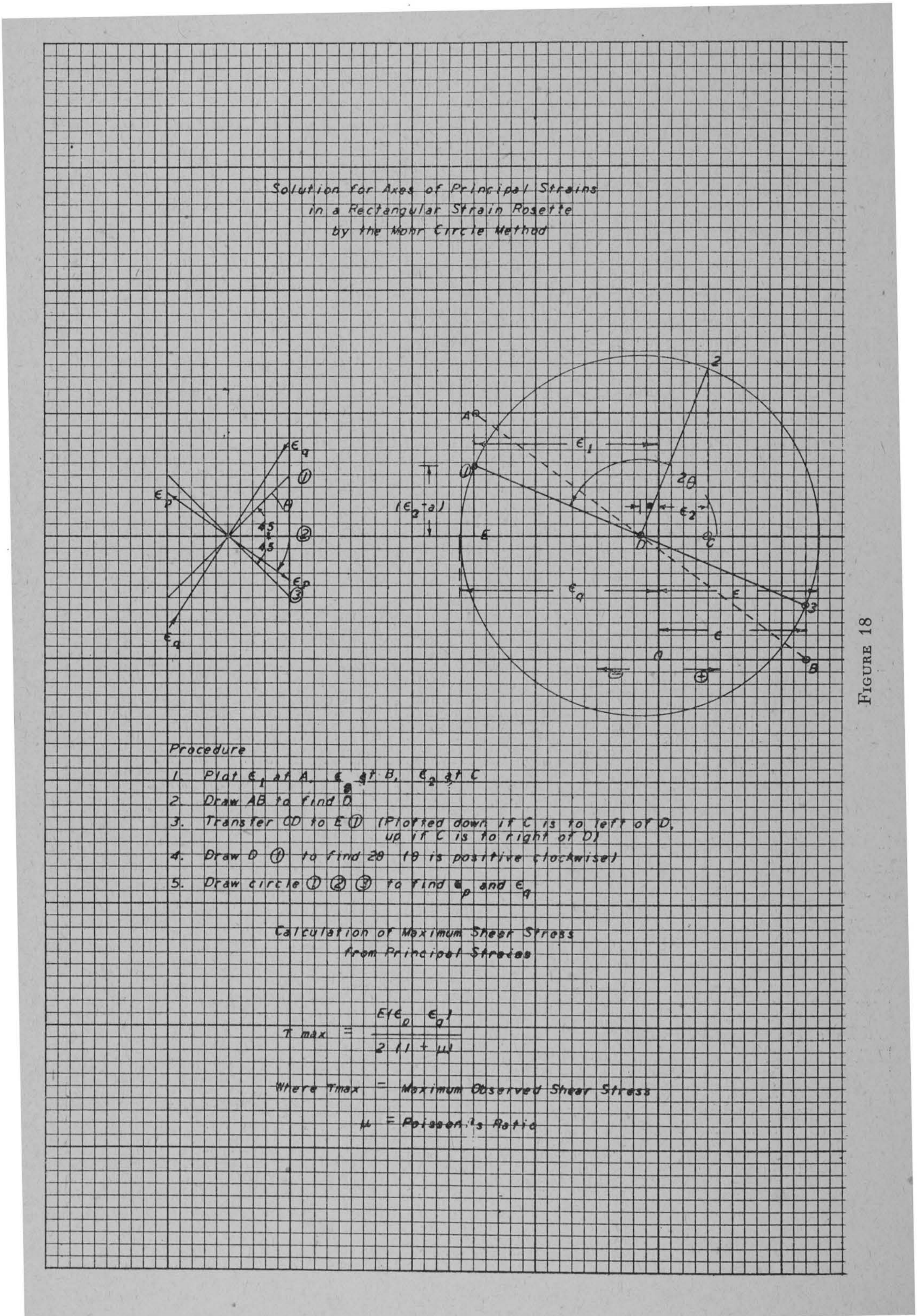

Solution for Axes of Principal Strains
in a Rectangular Strain Rosette
by the Mohr Circle Method
Procedure
1. Plot ε1 at A, ε3 at B, ε2 at C
2. Draw AB to find D
3. Transfer CD to E ① (Plotted down if C is to left of D, up if C is to right of D)
4. Draw D ① to find 2θ (θ is positive clockwise)
5. Draw circle ① ② ③ to find εp and εq
Calculation of Maximum Shear Stress
from Principal Strains
τ max = E(εp - εq) / 2 (1 + μ)
Where τmax = Maximum Observed Shear Stress
μ = Poisson's Ratio

FIGURE 18

OBSERVED SHEARING STRESS

AT 7,900 LBS.

Beam		Lbs. Per Sq. Inch
B-1	Tile-Concrete	210
B-2	Concrete	149
B-3	Tile-Concrete	186
B-4	Concrete	158
B-5	Precast 3" Tile-Concrete	170
B-7	Precast 6" Tile-Concrete	192
B-8	Precast 5" Tile Concrete	162
B-9	Precast 4" Tile-Concrete	205
C-1	Tile-Concrete, Buttered Joints	288
C-2	Tile-Concrete, Buttered Joints	153
C-3	Tile-Concrete, Buttered Joints	170
C-4	Tile-Concrete, Buttered Joints	167
Average for Concrete		154
Average for Tile-Concrete		190
Calculated Shear Stress		138

Most of the observations made to determine shearing stress resulted in satisfactory data; however, some of the data were either unreliable or else the composite type beam behaves in some manner not yet recognized in theory.

The average observed shearing stress at a 7,900-pound load for the concrete beams was 154 pounds per square inch as compared to 138 pounds calculated by the previously mentioned formula. This small difference does not seem to be significant, particularly since it is recognized that there is a concentration of stresses near the change in section at the joining of the web and the flange. The average shearing stress for the tile-concrete beam was 190 pounds per square inch as compared to 154 pounds per square inch for the concrete beam. Assuming the strain of these beams at the same point to be about the same, which it should be in identical, homogeneous beams, the difference in these stresses would correspond to the difference in their moduli of elasticity. The modulus of elasticity of the concrete was found to be about 3,000,000 pounds per square inch and for the tile to be about 3,700,000 pounds per square inch. The E for the concrete is 81% of the E for the tile. The average shearing stress at the 7,900 pound-load for the concrete is 154 pounds, which is 81% of 190 pounds, the average shearing stress for the tile-concrete. This check is good, but because of the variation of these observations between individual beams, this result does not justify the confidence which such check would ordinarily develop. The difference in observed shearing stresses seems to be due primarily to the difference in the modulus of elasticity of the two materials.

It is believed that the shearing stress formula, $v = \dfrac{V}{\frac{7}{8} b'd}$ is reasonably good for the average stress in a concrete beam, but for a tile-concrete beam the surface tile stress will differ according to the tile's modulus of elasticity.

By using a transformed area section and increasing the tile-concrete by the higher tile modulus of elasticity, it is calculated that the tile-concrete beam will have about 9% more transformed area and load carrying capacity because of the higher modulus of elasticity of the tile. As indicated previously the tile-concrete beams are about 38% stronger in diagonal tension than the concrete beam using this particular tile.

The remaining gain in strength is due to the greater strength of the tile and to the added strength of concrete from curing in the tile. If the tile used has approximately the same strength as concrete, it is believed there would be very little difference in the load carrying capacity of the concrete beams and the tile-concrete beams.

At first it was believed that a part of this gain in strength was due to existence of the outer shells. Figure 19 shows a typical load-strain curve for gages in a rosette on the outer shell. Observations were made on three beams and only one rosette out of six showed any appreciable strain. This one gage showed tensional strain in all three directions; therefore, these particular recordings do not seem to be reliable. This fact, along with other observations of the beams during the tests, seems to indicate that the outside shells do not add any appreciable diagonal tension strength.

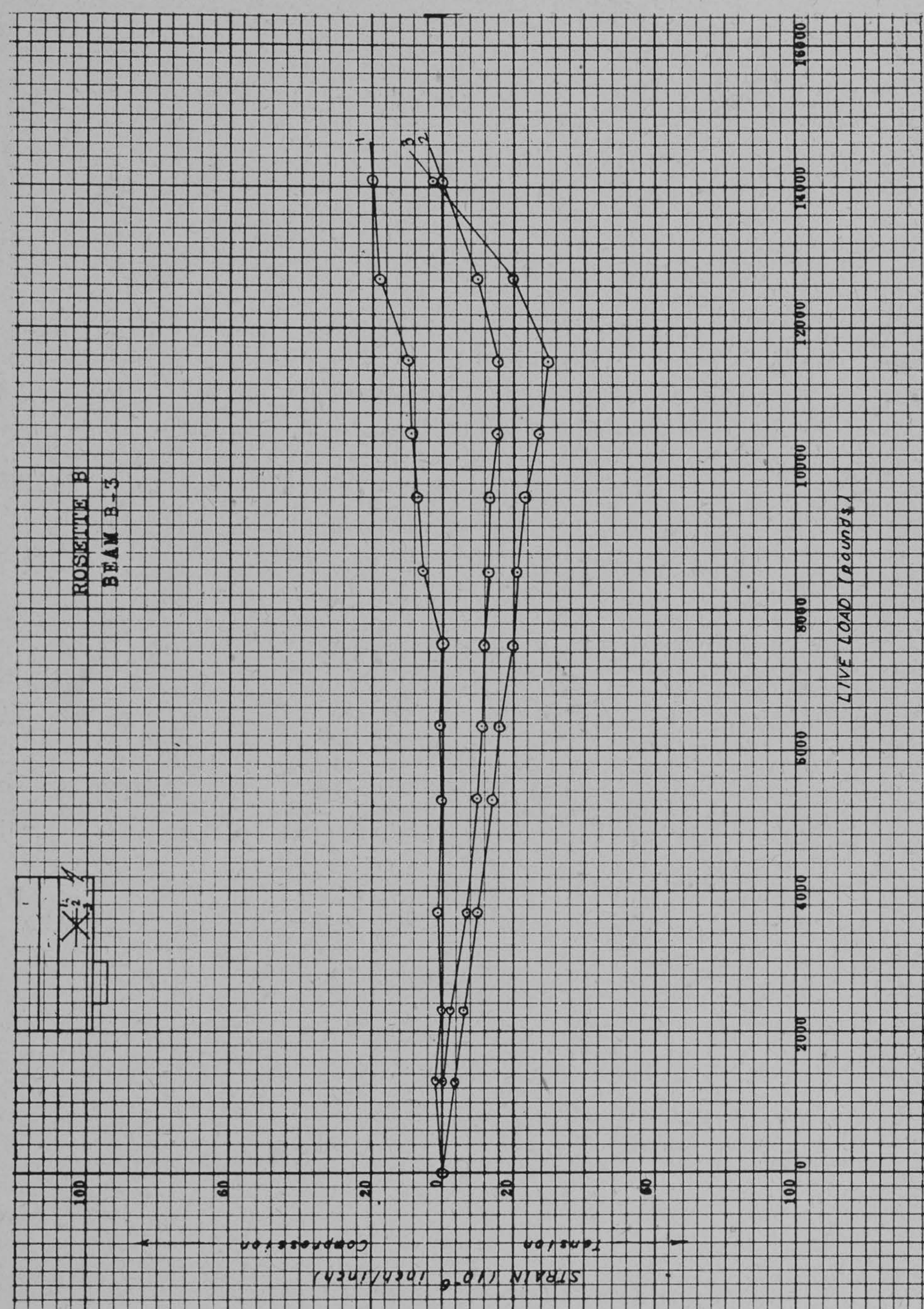

ROSETTE B
BEAM B-3
LIVE LOAD (pounds)
STRAIN (10^{-6} inch/inch)
Compression
Tension
0
2000
4000
6000
8000
10000
12000
14000
16000
100
60
20
0
20
60
100
1
2
3

FIGURE 19

APPENDIX

Appendix I

SUMMARY OF PRELIMINARY TESTS

Introduction

The purpose of this series of tests was to determine the various physical properties of tile in order that its true function in a tile-concrete beam could be evaluated. Considerable time was devoted to this phase of the program which was made difficult by the nature and shape of the manufactured product. The preparation of specimen for the different tests required considerable time. It was realized that the physical properties as detemined from these tests would not be the same for all tile that will be used in this investigation, but it was necessary to determine the approximate values. Tests were made on two lots of tile furnished by the Clay Products Institute.

Tests

T -1 to T -7:	Determination of stress-strain characteristics of Lot A tile in compression.
T -8:	Determination of compressive strengths of Lot B.
T -9:	Determination of tensile strength and tensile modulus of elasticity.
T-10 to T-11:	Determination of bond strength of concrete to tile.
T-12:	Absorption tests.

Properties

Modulus of elasticity in compression—3,600,000 pounds per square inch.

Modulus of elasticity in tension—3,700,000 pounds per square inch.

Compressive strength—6,240 to 10,800 pounds per square inch.

Tensile strength—650 to 1,100 pounds per square inch.

Bond strength (w/c = 7.27 gals/sack)—380 lbs./sq. in.

Absorption—5.66%.

Stress-Strain Characteristics in Compression

Tests T-1 through T-7 were compression tests conducted on one Lot A beam tile block; in T-1 and T-2 the cap that is to be removed when the tile is to be used in a beam was left on and the net area of the section determined.

The center of gravity axes were determined and four SR-4 A-type resistance strain gages were attached at the apparent center of gravity. The cap on the tile was fractured during the fourth run of test T-2. Stress-strain curves for each gage and an average for all gages were drawn and the modulus of elasticity determined.

In T-3 the center of gravity of the section without the cap was determined and two additional strain gages were attached to the tile on the new center of gravity. Stress-strain curves for the five gages and averages for all gages were determined and the apparent modulus of elasticity determined from these curves.

In T-4 the strain gages on the old center of gravity were removed and stress-strain curves for the remaining three gages were run and the apparent modulus of elasticity determined.

In tests T-5, T-6, and T-7, two additional strain gages were attached to the inner webs as near the center of gravity as possible and stress-strain curves were determined. In T-5 the gages that were attached to the webs did not function satisfactorily, so they were removed and two others were attached before running tests T-6 and T-7.

The following is the average modulus of elasticity of tile as determined from each test:

T-1	3,560,000 lbs. per sq. inch.
T-2	3,549,000 lbs. per sq. inch.
T-3	3,930,000 lbs. per sq. inch.
T-4	3,660,000 lbs. per sq. inch.
T-5	3,210,000 lbs. per sq. inch.
T-6	3,865,000 lbs. per sq. inch.
T-7	3,530,000 lbs. per sq. inch.

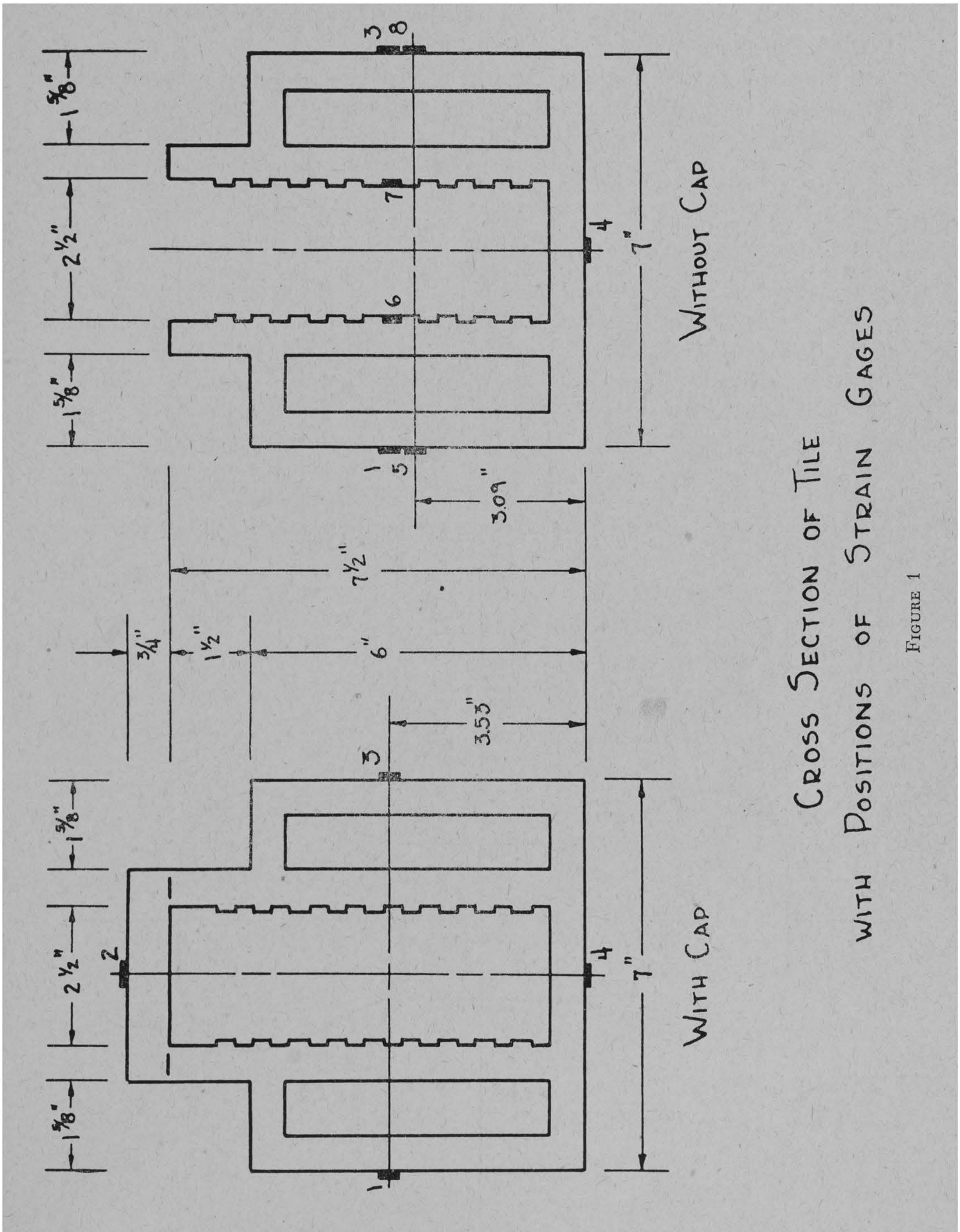
From the above tests, it was concluded that the modulus of elasticity of the tile in compression was approximately 3,600,000 pounds per square inch.

Considerable difficulty was experienced in performing these tests because of the unsymmetrical cross-section of the tile. Extensive tests were justified because of the importance of knowing the modulus of elasticity of tile as accurately as possible in future stress-strain analyses of the tile beam.

All of these tests were made on Lot A tile. It did not seem necessary to make similar tests on Lot B tile because the tensile modulus of elasticity was the same for Lot A and Lot B tile.

Compressive Strength

Test T-8 was made to determine the compressive strength of Lot A tile sections. The specimens were shellacked and the section capped with plaster. The tile caps were removed from two specimens and were left on two specimens. These caps sheared off the specimens on which they were left at about an average stress of 5,000 pounds per square inch. The sections with the cap removed before testing carried an average stress of 10,800



Cross Section of Tile with Positions of Strain Gages

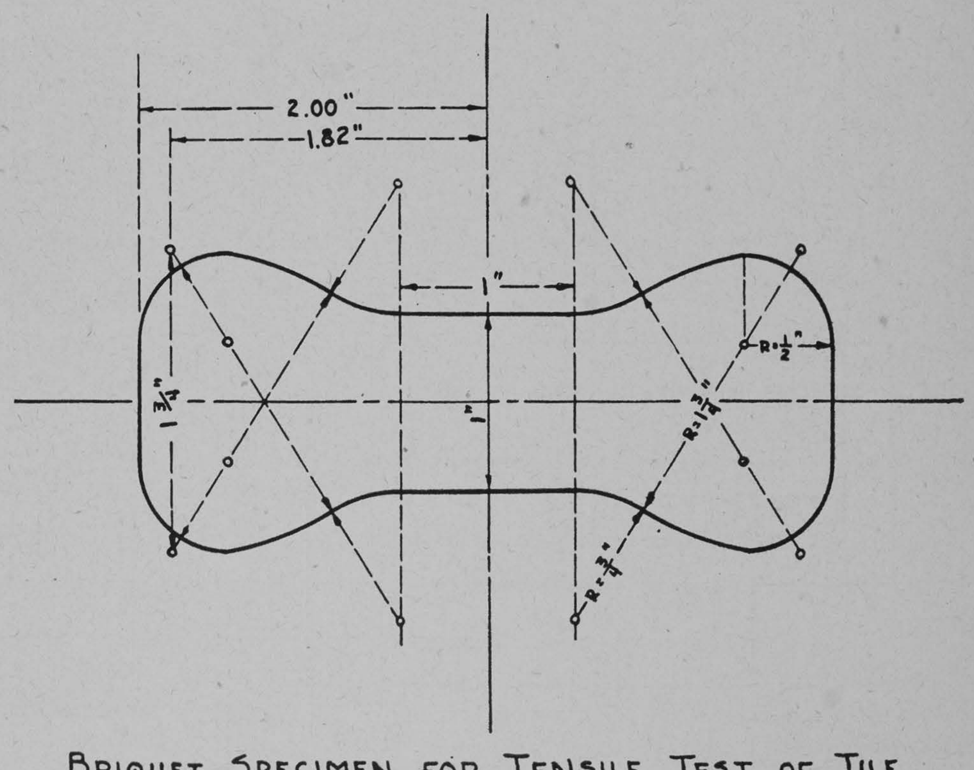
Figure 1

pounds per square inch as compared to 8,940 pound per square inch average for the specimen with caps at start of loading. The failures were a combination of vertical shear and web bending.

A stock of Lot B tile subsequently received were tested without caps. Because a high percentage of this tile contained shrinkage cracks, one sound tile and one cracked tile were tested. The sound tile carried 8,280 pounds per square inch as compared to 6,240 pounds per square inch for the cracked tile.

Stress-Strain Characteristics in Tension

In Test T-9 a briquet specimen was designed by extending the center section of the ASTM Standard concrete mortar briquet to a length of one inch. The cutting of these briquets was a tedious task and required considerable time and diligence before satisfactory specimen could be secured. The first four specimens were cut from the caps that were removed from the tile sections of the Lot A tile. Two SR-4 A-type resistance strain gages were attached on opposite sides of one specimen and a stress-strain curve was run on the specimen to determine the modulus of elasticity in tension. An ASTM Standard concrete mortar briquet tensile testing machine was used



BRIQUET SPECIMEN FOR TENSILE TEST OF TILE

FIGURE 2

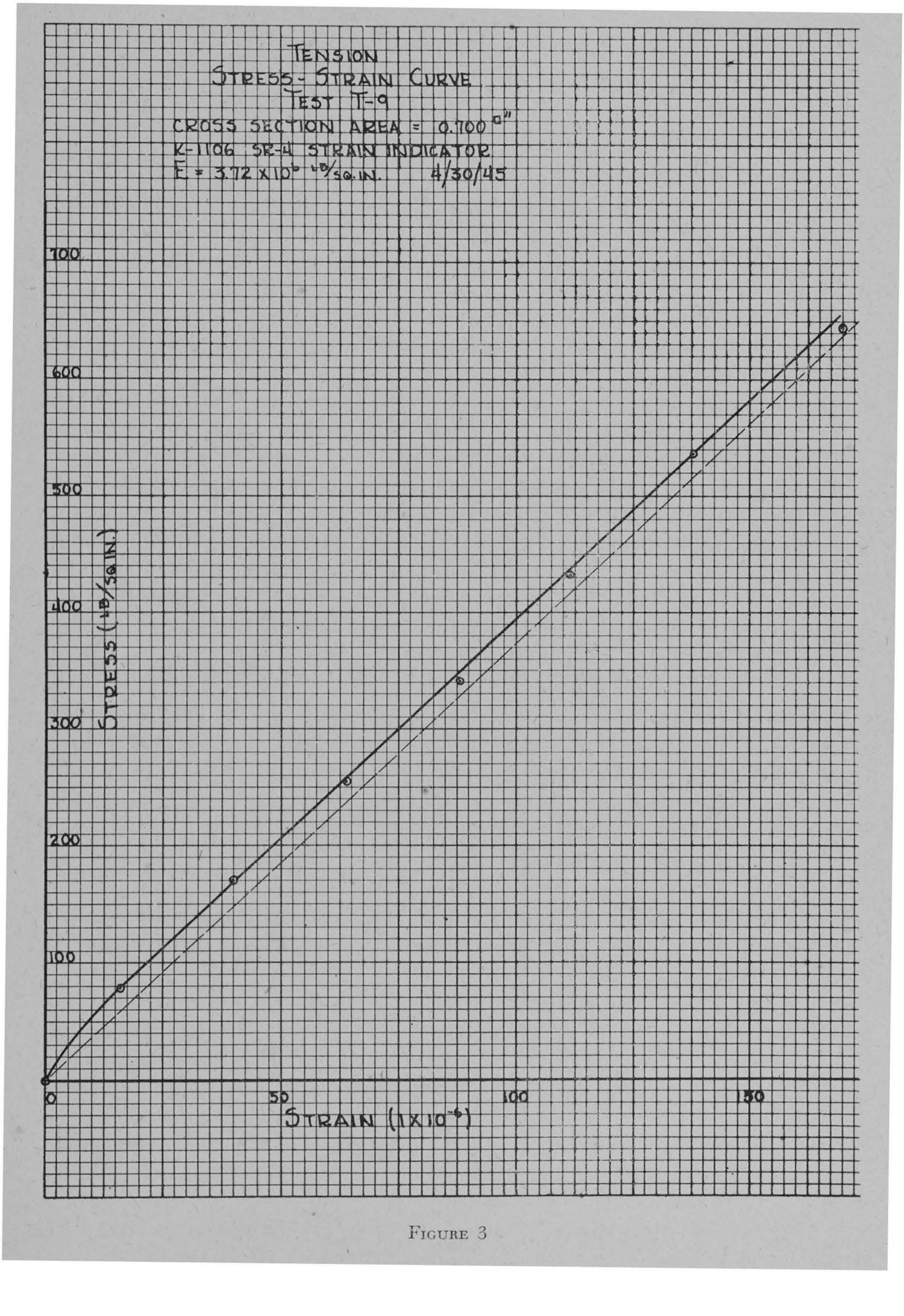

TENSION
STRESS - STRAIN CURVE
TEST T-9
CROSS SECTION AREA = 0.700 □"
K-1106 SR-4 STRAIN INDICATOR
E = 3.72 x 10⁶ LB/SQ.IN. 4/30/45
STRESS (LB/SQ.IN.)
700
600
500
400
300
200
100
0
50
100
150
STRAIN (1 x 10⁻⁶)

FIGURE 3

in the tests. The modulus of elasticity in tension was found to be 3,700,000 pounds per square inch. The same procedure was followed in testing a briquet from the Lot B tile which had a 3,700,000 pounds per square inch modulus of elasticity also.

Tensile Strength

Briquets were cut from the outer webs of the tile. These briquets were cut with the axis of the briquet along the longitudinal axis of the tile and with the axis of the briquet perpendicular to the longitudinal axis of the tile. The following tabulation is the average tensile strength in pounds per square inch of at least three briquets:

	Specimen Along Tile	Specimen Across Tile
Lot A	1,100	890
Lot B	780	650

Bond Strength

Test T-10 was conducted in an attempt to determine the bond strength between the tile and concrete. A fiber board was placed in the center of a tile and a ¾″ steel plate with a 1″ round bar welded at the center of gravity of the perimeter of the tile section was placed on each side of the division with the bars extending out the end of the tile sufficiently so that they could be gripped in a testing machine. Concrete made with "pea" gravel was used to fill the tile. The concrete was cured with moist cement sacks for seven (7) days. At the age of eight days, the tile was placed in the testing machine and a tensile load applied through the steel bars. The tile failed at the center section at an average tensile stress of 441 pounds per square inch, which was an average bond stress of 135 pounds per square inch.

These two pieces of the specimen were then subjected to push-out tests by placing the bar down into a tile section so that the concrete was unsupported. This test was not successful in determining the bond value because the bending stresses set up due to the eccentric load caused the tile to pop off the concrete. The average bond stress was only 161 pounds per square inch.

The next bond test, T-11, was made by pouring concrete into a tile section and cutting the section into approximately 2, 4, 6, and 10-inch lengths. The specimens were tested in a push-out test using a cast iron bearing block cut so that the concrete was unsupported. The longer sections failed from bending rather than from bond. The two-inch length failed at a bond stress of 378 pounds per square inch. The results of the tests indicated that this is approximately the bond strength of the tile and concrete with a water factor of 7.27 gallons per sack.

T-12 was a standard ASTM absorption test for tile. Average absorption was found to be 5.66 per cent.

Appendix II

BEAM TESTS

The following data are a record of the beam tests made in this investigation. Included are tables summarizing each series of tests and diagrams of each beam. Data are in the following order:

Series I
B-1
B-2
B-3
B-4

Series II
B-5
B-6
B-7
B-8
B-9

Series III
C-1
C-2
C-3
C-4

THE UNIVERSITY OF TEXAS

Bureau of Engineering Research

Tile Beam Research

Beam	B-1	B-2	B-3	B-4
Type	Tile-Concrete	Concrete	Tile-Concrete	Concrete
Load at first crack	15,170	12,130	12,700	11,130
Ultimate Load	16,900	12,130	15,700	11,130
Deflection, 5,000lb	0.036″	0.042″	0.049″	0.050″
Deflection, 10,000lb	0.086″	0.100″	0.101″	0.105″
Deflection, 7,900lb	0.064″	0.071″	0.079″	0.079″
Last Deflection Reading	16,900— 0.270″	12,130— 0.160″	12,700— 0.140″	11,130— 0.144″
Observed Shearing Stress, 7,900lb	210lb/sq.″	149lb/sq.″	186lb/sq.″	158lb/sq.″
Calculated Shearing Stress, 7,900lb	138lb/sq.″	138lb/sq.″	138lb/sq.″	138lb/sq.″
Calculated Shearing Stress at Failure	294lb/sq.″	212lb/sq.″	274lb/sq.″	194lb/sq.″
Type of Failure	Diag. Ten.	Diag. Ten.	Diag. Ten.	Diag. Ten.
Comp. Strength of Concrete	3,400lb/sq.″	3,400lb/sq.″	3,200lb/sq.″	3,400lb/sq.″

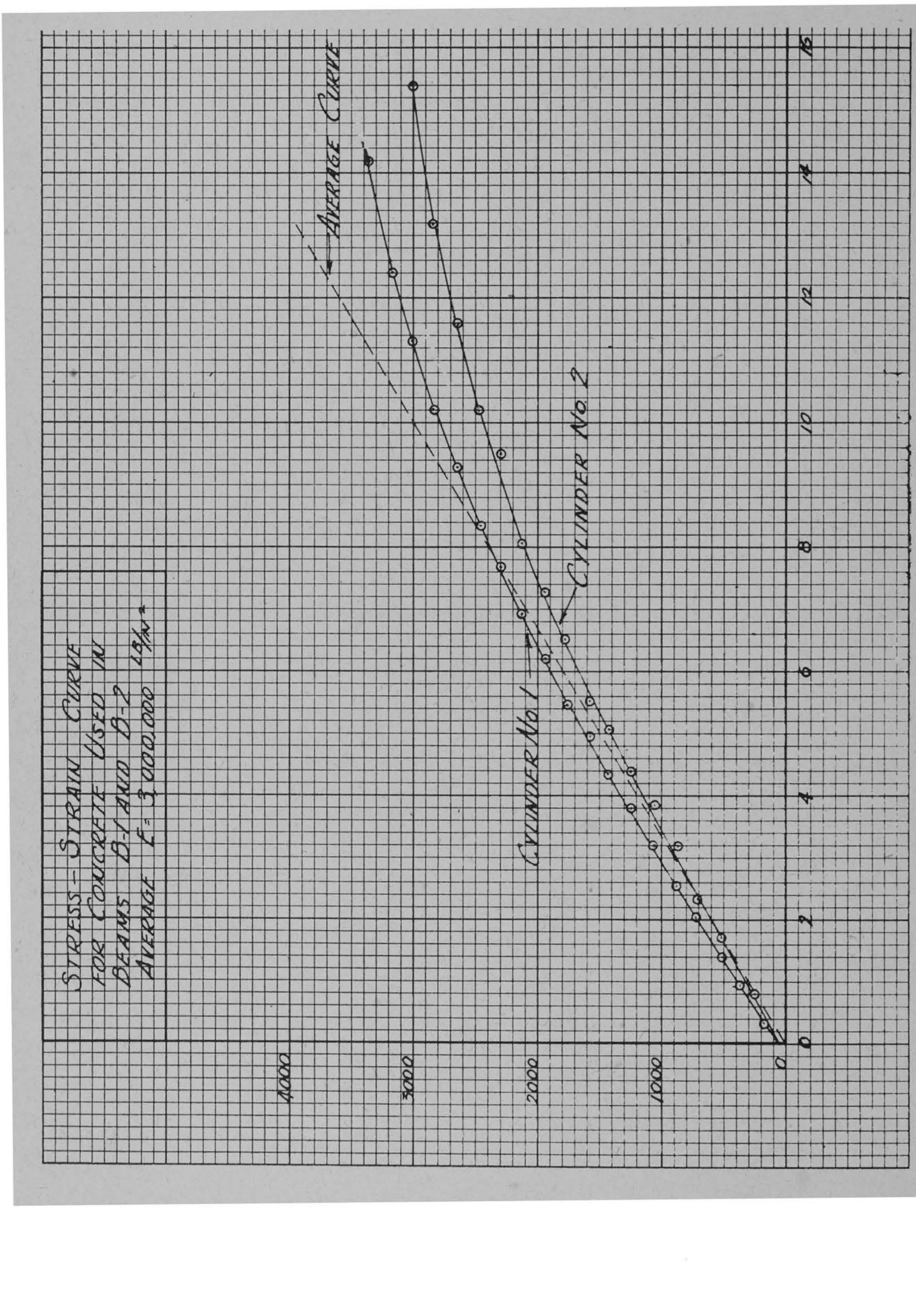
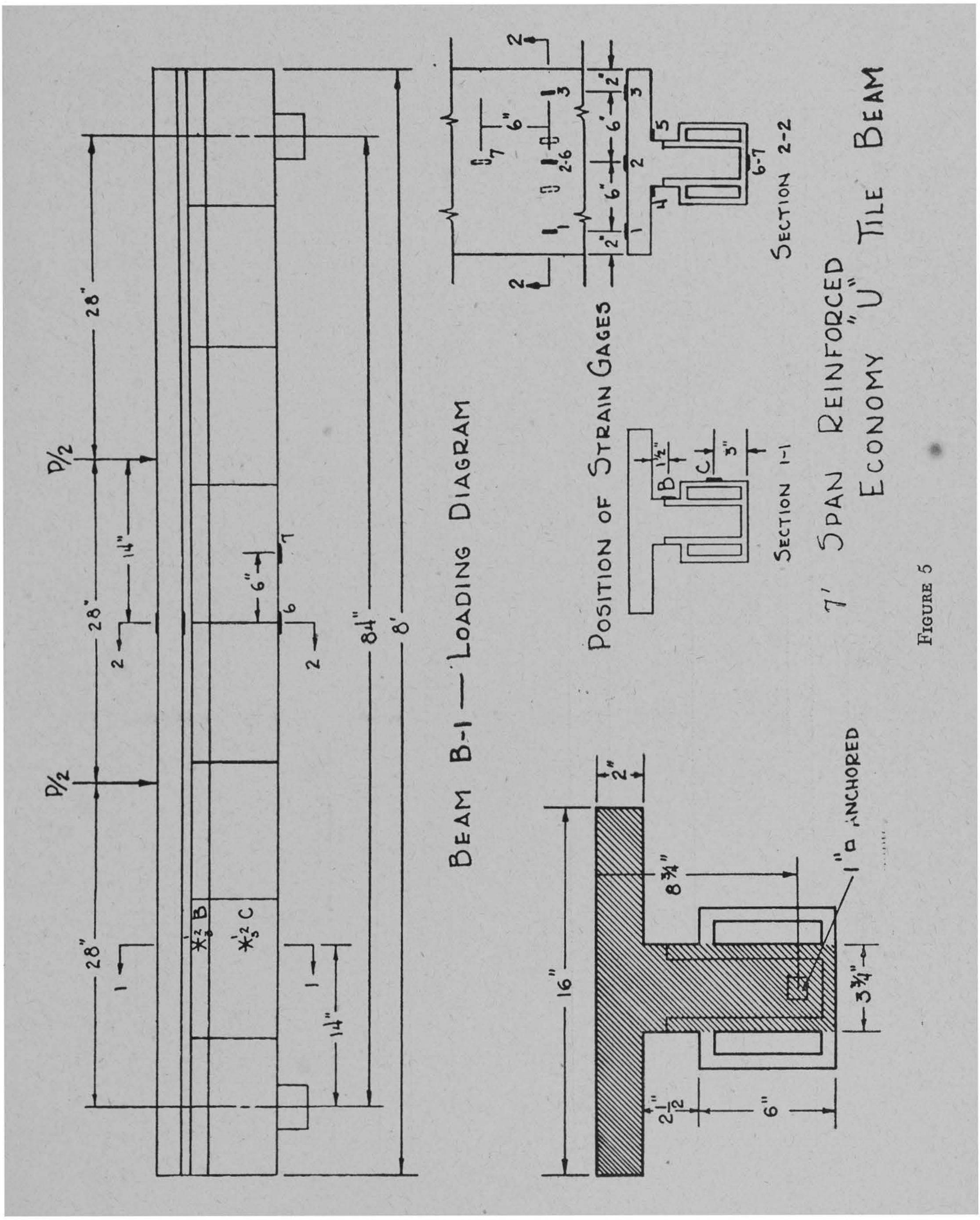

STRESS-STRAIN CURVE
FOR CONCRETE USED IN
BEAMS B-1 AND B-2
AVERAGE E=3,000,000 LB/IN²
AVERAGE CURVE
CYLINDER No 1
CYLINDER No 2
0
1000
2000
3000
4000
0
2
4
6
8
10
12
14
16

FIGURE 4



BEAM B-1 — LOADING DIAGRAM
P/2
P/2
28"
28"
28"
14"
14"
6"
84"
8'
POSITION OF STRAIN GAGES
SECTION 1-1
SECTION 2-2
1" ▫ ANCHORED
16"
2"
8¾"
3¾"
2½"
6"
7' SPAN REINFORCED ECONOMY "U" TILE BEAM

FIGURE 5

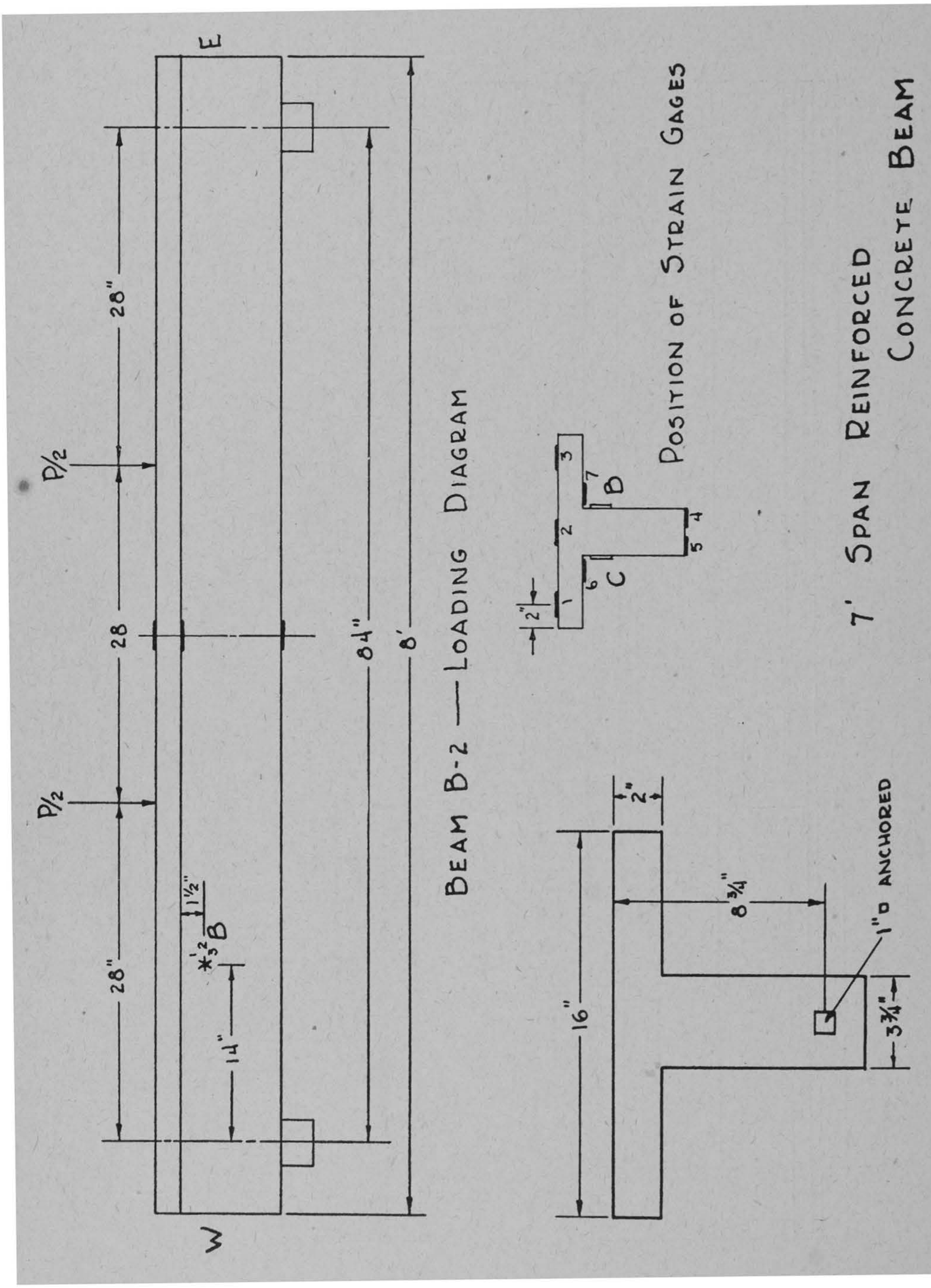

W
E
P/2
P/2
28"
28
28"
14"
1½"
B
84"
8'
BEAM B-2 — LOADING DIAGRAM
16"
2"
8¾"
3¾"
1"D ANCHORED
2"
1
2
3
4
5
6
7
C
B
POSITION OF STRAIN GAGES
7' SPAN REINFORCED CONCRETE BEAM

FIGURE 6

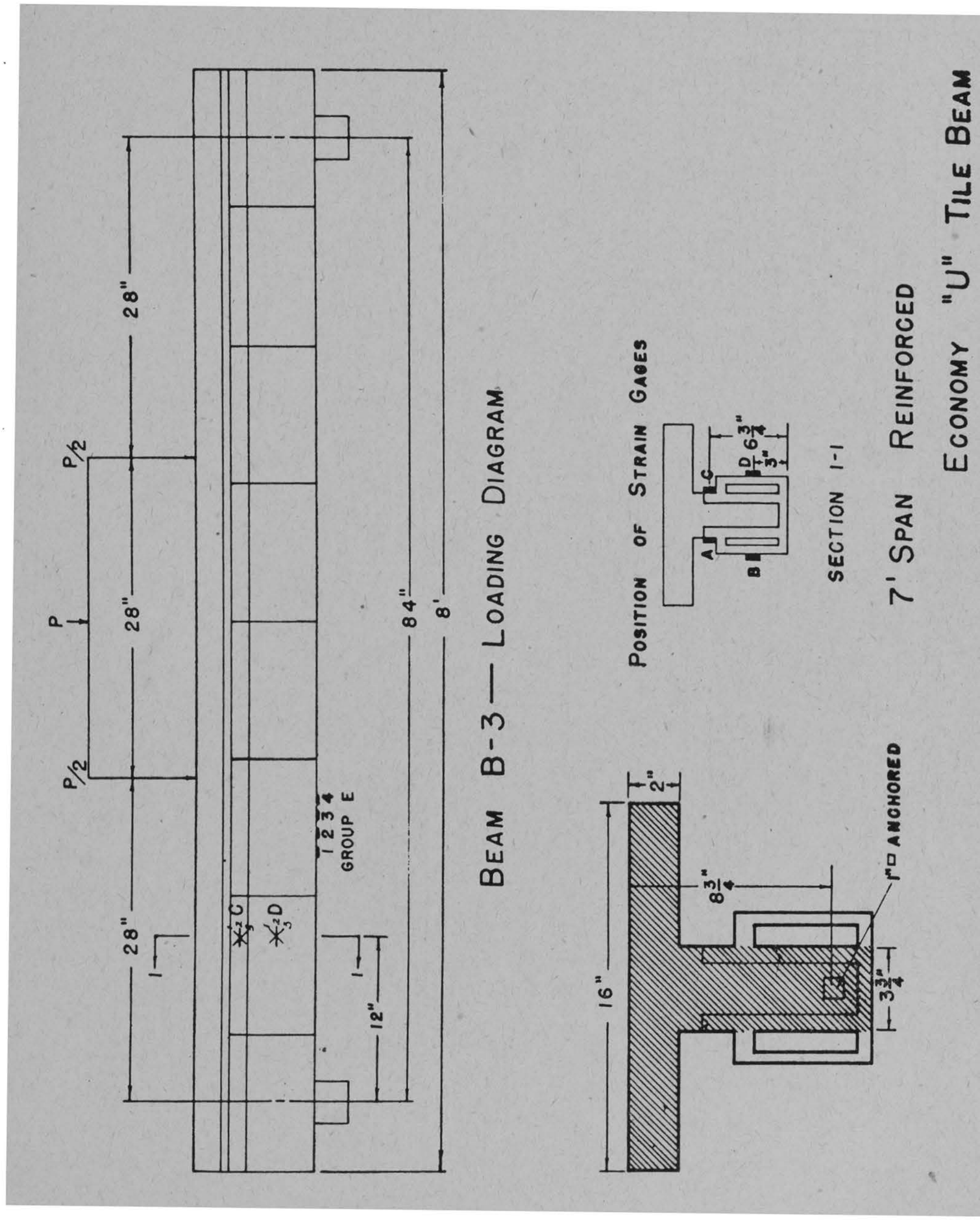

P/2
P
P/2
28"
28"
28"
1
1
1 2 3 4
GROUP E
12"
84"
8'
BEAM B-3 — LOADING DIAGRAM
16"
2"
8 3/4"
3 3/4"
1"□ ANCHORED
POSITION OF STRAIN GAGES
A
B
C
D
6 3/4"
3"
SECTION 1-1
7' SPAN REINFORCED
ECONOMY "U" TILE BEAM

FIGURE 7

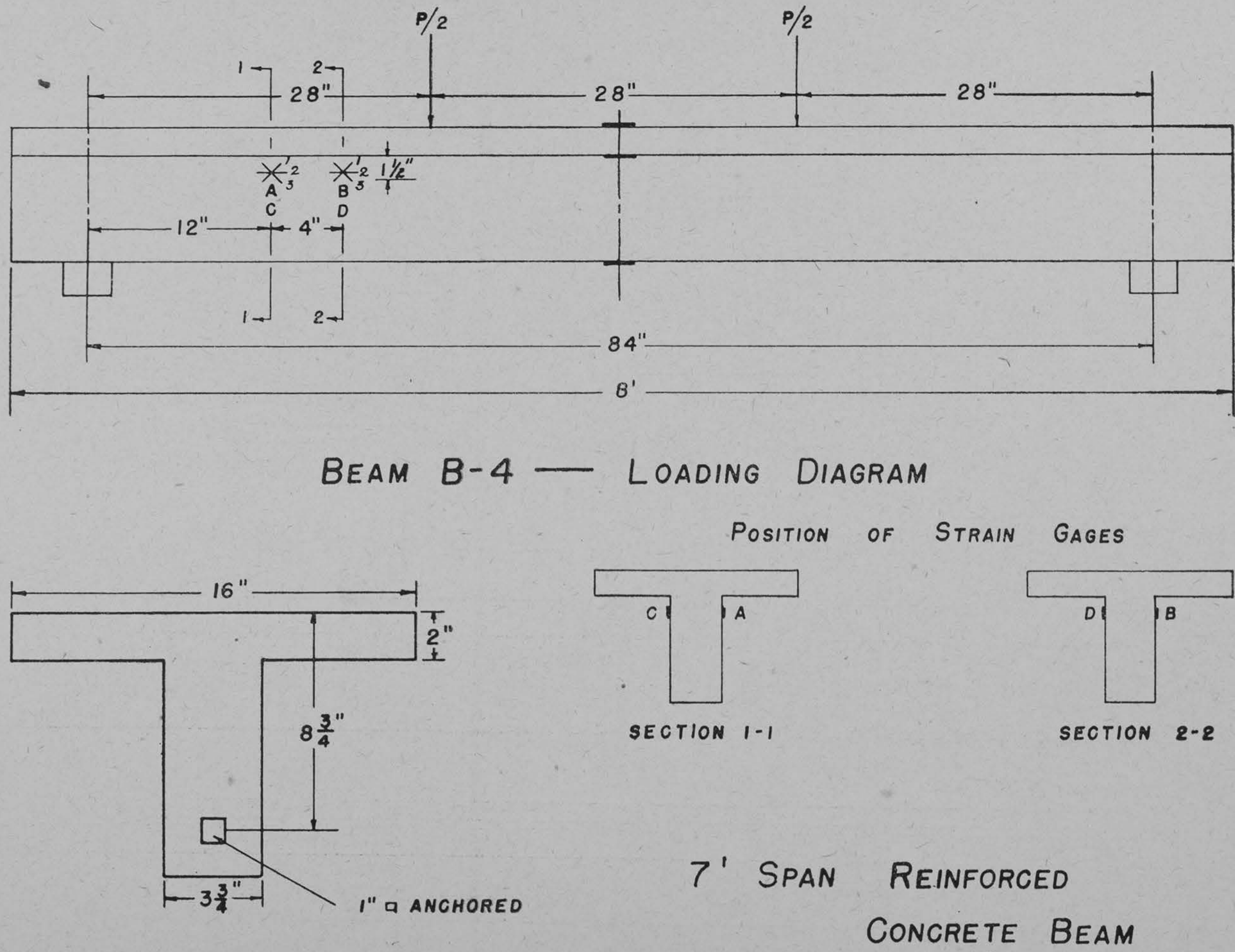

P/2
P/2
28"
28"
28"
12"
4"
1½"
84"
8'
BEAM B-4 — LOADING DIAGRAM
POSITION OF STRAIN GAGES
16"
2"
8¾"
3¾"
1" ◻ ANCHORED
SECTION 1-1
SECTION 2-2
7' SPAN REINFORCED
CONCRETE BEAM

Figure 8

THE UNIVERSITY OF TEXAS

Bureau of Engineering Research

Tile Beam Research

Beam	B-5	B-6	B-7	B-8	B-9
Type	Precast 3″ Tile-Concrete	Precast 6¾″ Tile-Concrete	Precast 6″ Tile-Concrete	Precast 5″ Tile-Concrete	Precast 4″ Tile-Concrete
Load at first crack	14,100		15,650lb	14,000lb	15,800lb
Ultimate Load	16,300	10,260lb	17,450lb	16,000lb	15,800lb
Deflection, 5,000lb	0.039″	0.117″	0.040″	0.046″	0.041″
Deflection, 10,000lb	0.084″	0.400″	0.091″	0.096″	0.081″
Deflection, 7,900lb	0.065″	0.256″	0.070″	0.072″	0.065″
Last Deflection Reading	16,300—0.260″	10,260lb 0.520″	16,500lb—0.180″	16,000—0.250″	15,800—0.149″
Observed Shearing Stress, 7,900lb	170lb/sq.″		192lb/sq.″	162lb/sq.″	205lb/sq.″
Calculated Shearing Stress, 7,900lb	138lb/sq.″	138lb/sq.″	138lb/sq.″	138lb/sq.″	138lb/sq.″
Calculated Shearing Stress at Failure	285lb/sq.″	179lb/sq.″	304lb/sq.″	279lb/sq.″	276lb/sq.″
Type of Failure	Diag. Ten.	Comp. in Concrete	Diag. Ten.	Diag. Ten.	Diag. Ten.
Comp. Strength of Concrete	3,500lb/sq.″	3,500lb/sq.″	3,300lb/sq.″	3,300lb/sq.″	3,600lb/sq.″

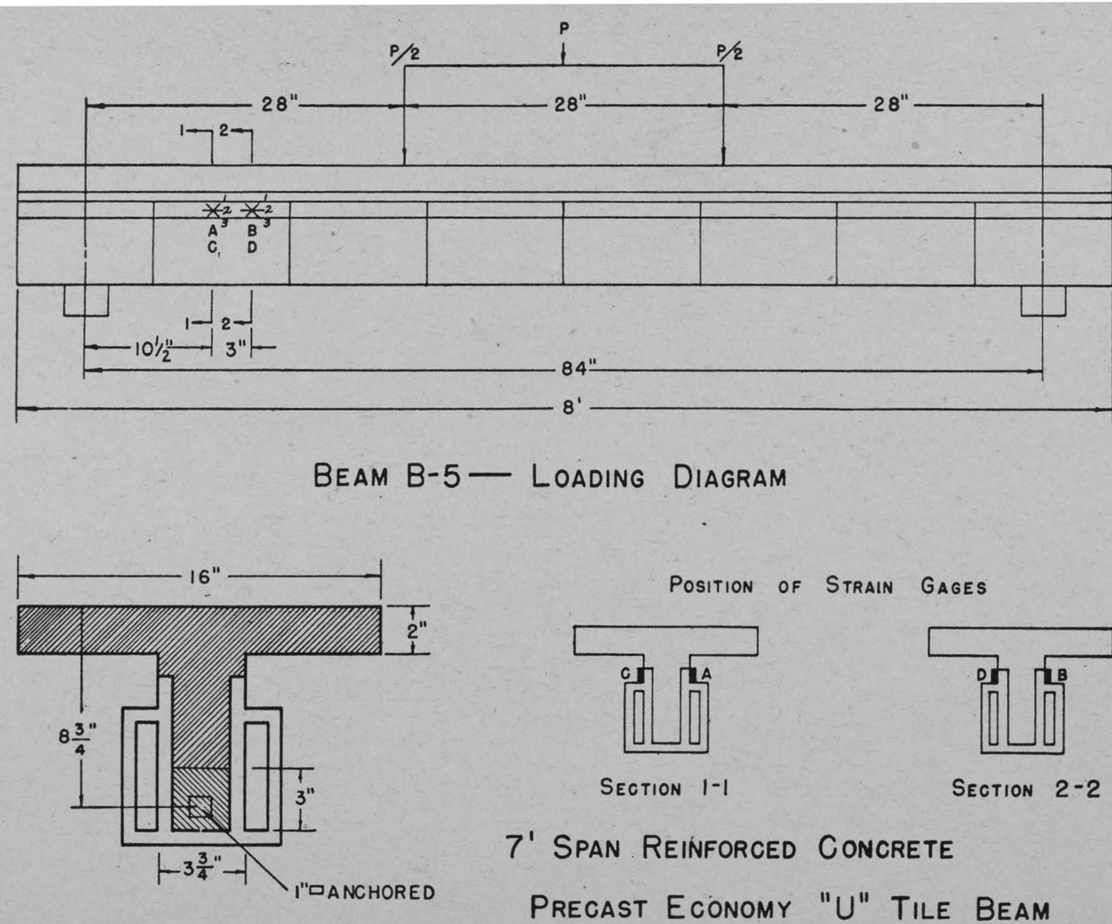
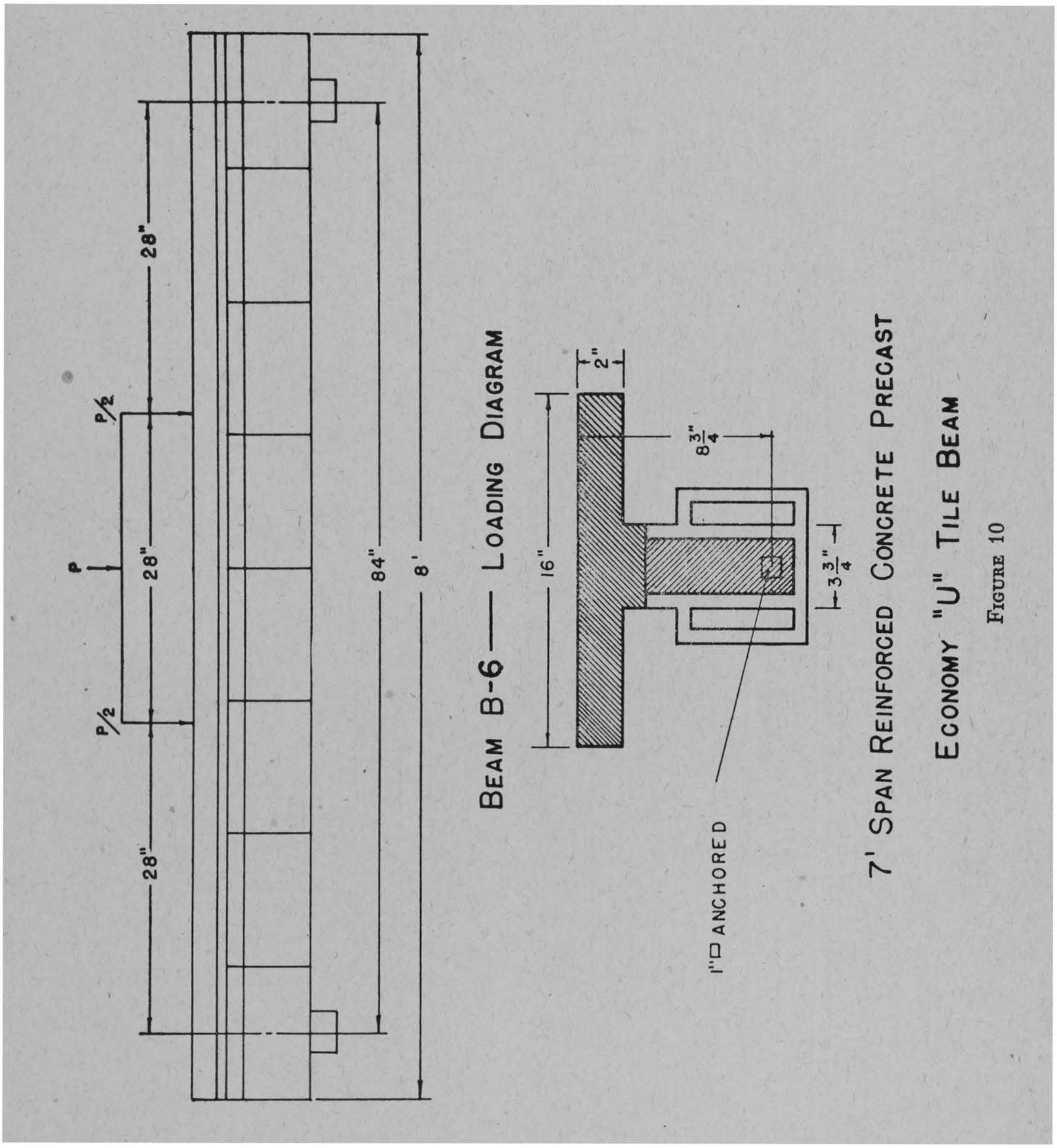

P
P/2
P/2
28"
28"
28"
1
2
A
B
C
D
10½"
3"
84"
8'
BEAM B-5 — LOADING DIAGRAM
16"
2"
8¾"
3"
3¾"
1" ANCHORED
POSITION OF STRAIN GAGES
SECTION 1-1
SECTION 2-2
7' SPAN REINFORCED CONCRETE
PRECAST ECONOMY "U" TILE BEAM

FIGURE 9



BEAM B-6 — LOADING DIAGRAM

7' SPAN REINFORCED CONCRETE PRECAST

ECONOMY "U" TILE BEAM

FIGURE 10

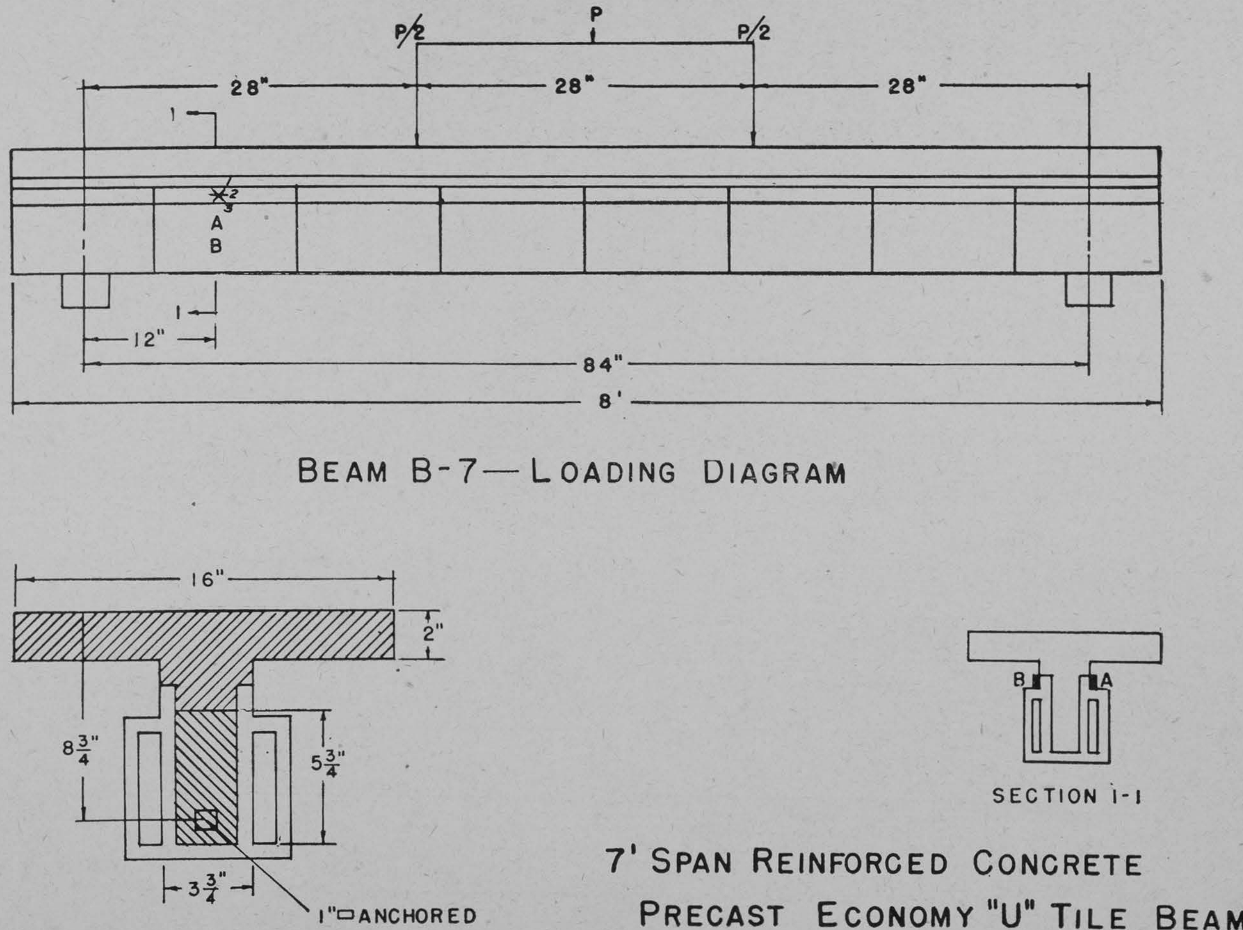

P
P/2
P/2
28"
28"
28"
1
A
B
1
12"
84"
8'
BEAM B-7—LOADING DIAGRAM
16"
2"
8 3/4"
5 3/4"
3 3/4"
1" ANCHORED
B
A
SECTION 1-1
7' SPAN REINFORCED CONCRETE
PRECAST ECONOMY "U" TILE BEAM

FIGURE 11

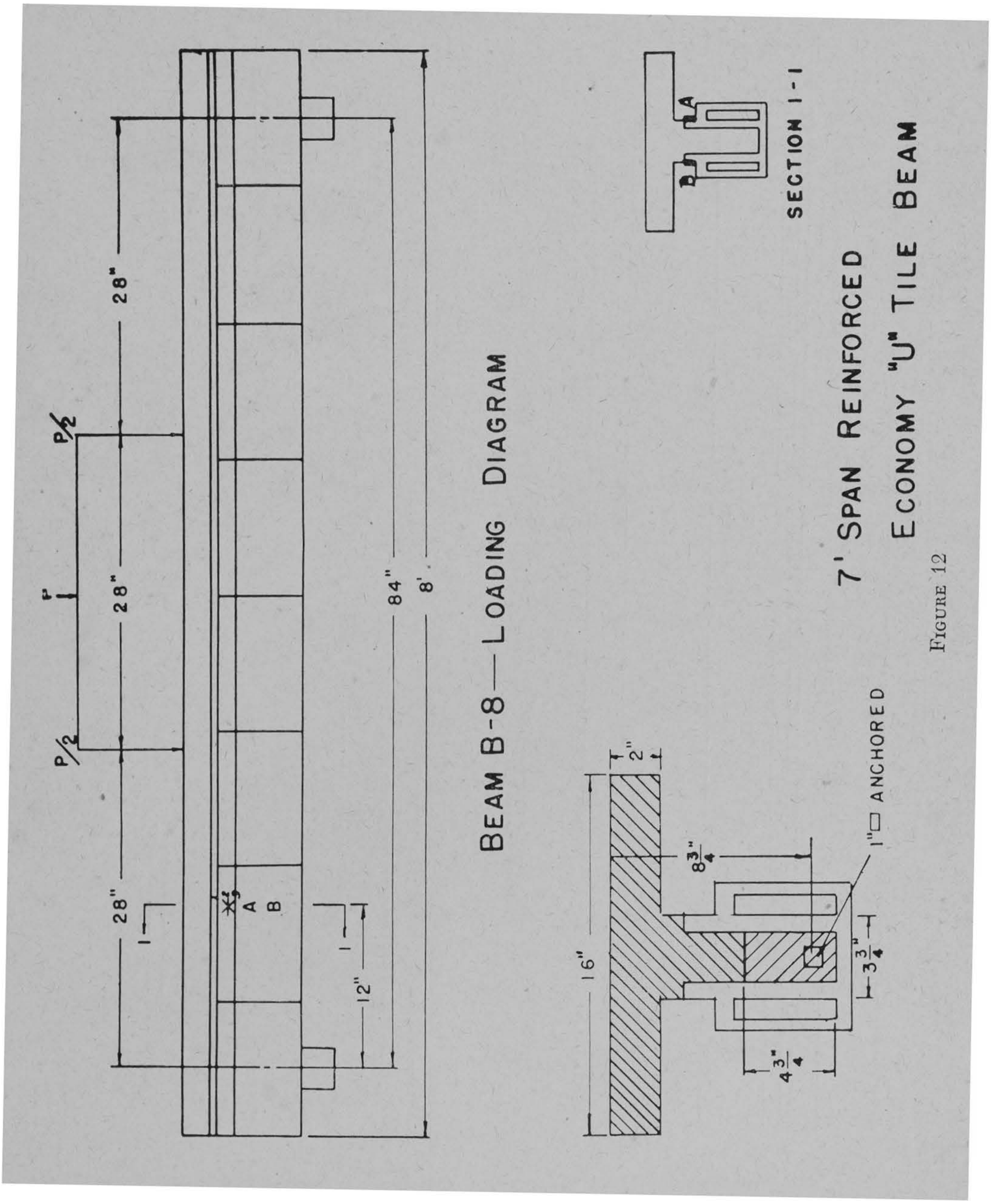

BEAM B-8 — LOADING DIAGRAM
P
P/2
P/2
28"
28"
28"
84"
8'
12"
16"
2"
$8\frac{3}{4}$"
$4\frac{3}{4}$"
$3\frac{3}{4}$"
1"□ ANCHORED
SECTION 1-1
7' SPAN REINFORCED
ECONOMY "U" TILE BEAM

FIGURE 12

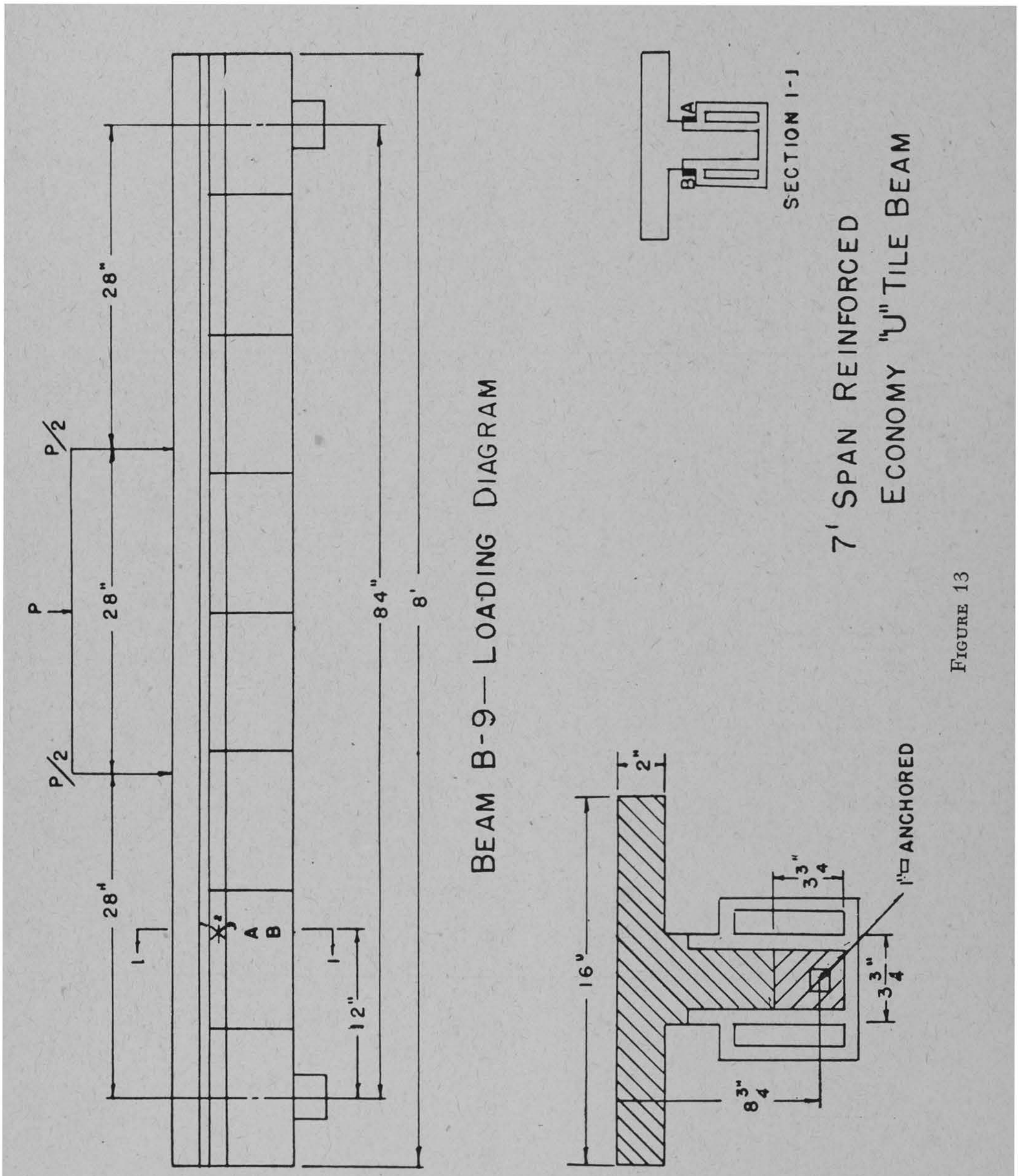

P/2
P
P/2
28"
28"
28"
84"
8'
12"
A
B
1-1
BEAM B-9—LOADING DIAGRAM
SECTION 1-1
16"
2"
3 3/4"
3 3/4"
8 3/4"
1"□ ANCHORED
7' SPAN REINFORCED
ECONOMY "U" TILE BEAM

FIGURE 13

THE UNIVERSITY OF TEXAS

Bureau of Engineering Research

Tile Beam Research

Beam	C-1	C-2	C-3	C-4
Type	Tile-Conc. Buttered Joints	Tile-Conc. Buttered Joints	Tile-Conc. Buttered Joints	Tile-Conc. Buttered Joints
Load at first crack	15,860℔	17,030℔	12,990℔	14,810℔
Ultimate Load	15,860℔	17,030℔	12,990℔	14,810℔
Deflection, 5,000℔	0.041″	0.037″	0.041″	0.040″
Deflection, 7,900℔	0.065″	0.057″	0.066″	0.063″
Deflection, 10,000℔	0.085″	0.074″	0.084″	0.080″
Last Deflection Reading	13,300℔—0.118″	17,030℔—0.150″	11,490℔—0.198″	14,810℔—0.130″
Observed Shearing Stress, 7,900℔	288℔/sq.″	153℔/sq.″	170℔/sq.″	167℔/sq.″
Calculated Shearing Stress, 7,900℔	138℔/sq.″	138℔/sq.″	138℔/sq.″	138℔/sq.″
Calculated Shearing Stress at Failure	277℔/sq.″	296℔/sq.″	266℔/sq.″	258℔/sq.″
Type of Failure	Dia. Ten.	Dia. Ten.	Dia. Ten.	Dia. Ten.
Comp. Strength of Concrete	3,000℔/sq.″	3,300℔/sq.″	2,850℔/sq.″	3,150℔/sq.″

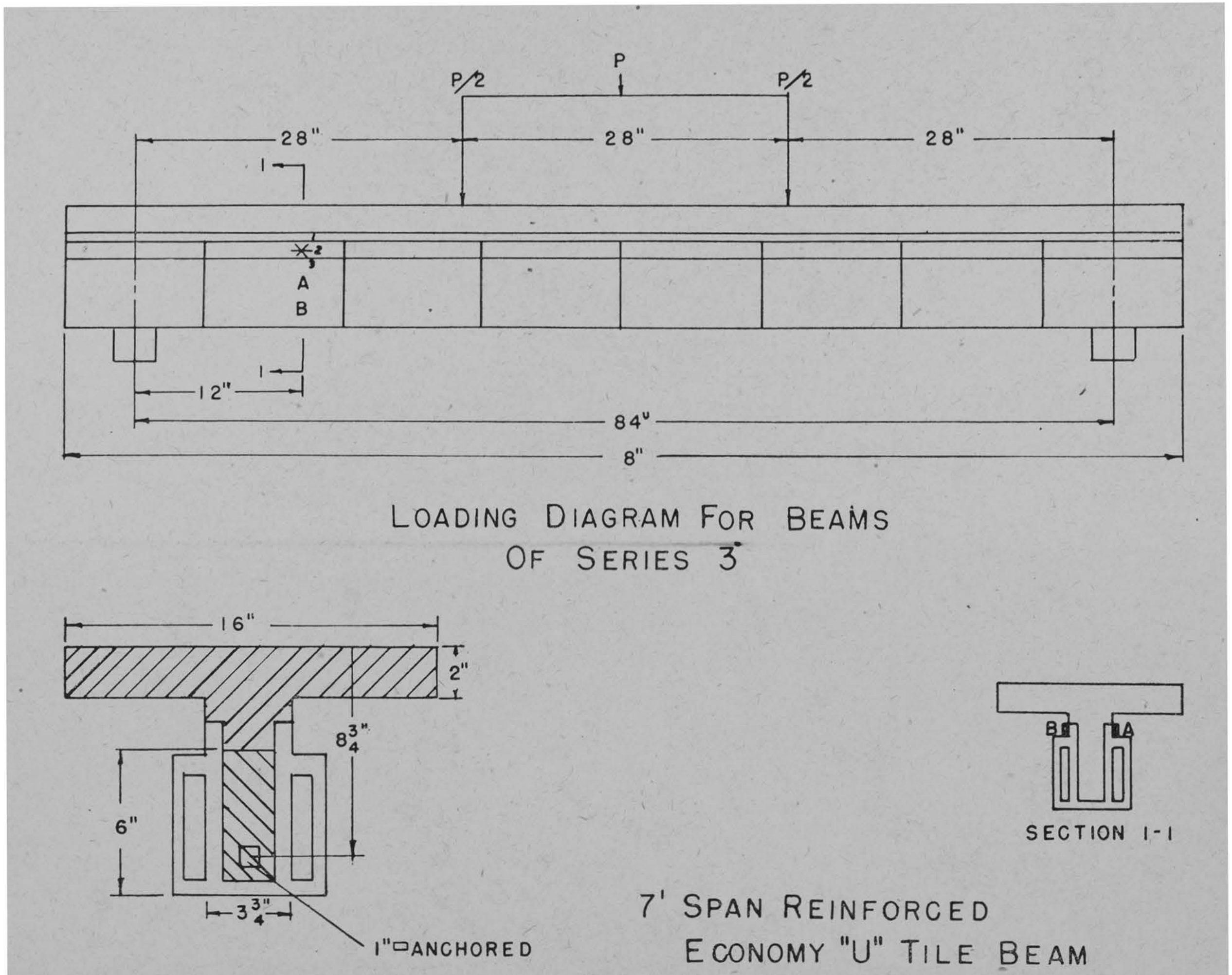

P
P/2
P/2
28"
28"
28"
1
A
B
1
12"
84"
8"
LOADING DIAGRAM FOR BEAMS
OF SERIES 3
16"
2"
$8\frac{3}{4}$"
6"
$3\frac{3}{4}$"
1"□ ANCHORED
B
A
SECTION 1-1
7' SPAN REINFORCED
ECONOMY "U" TILE BEAM

FIGURE 14

PUBLICATIONS OF THE BUREAU OF ENGINEERING RESEARCH†

*1. Bulletin No. 16. Rice Irrigation in Texas, by T. U. Taylor. 1902.
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*16. Bulletin No. 1815. Physical Properties of Dense Concrete as Determined by the Relative Quantity of Cement, by F. E. Giesecke and S. P. Finch. 1918.
*17. Bulletin No. 1839. Road Building Materials in Texas, by J. P. Nash, coöperation with C. L. Baker, E. L. Porch, and R. G. Tyler. 1918.
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20. Bulletin No. 2215. Progress Report of the Engineering Research Division of the Bureau of Economic Geology and Technology, by F. E. Giesecke, H. R. Thomas, and G. A. Parkinson. 1922.
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§39. Bulletin No. 4407. The Architectonic City in the Americas, by Hugo Leipziger, 1944.
40. Bulletin No. 4432. The Specific Heat of Foodstuffs, by Byron E. Short and Luis H. Bartlett. 1944.
41. Bulletin No. ——. An Investigation of "U' Type Tile-Concrete Beams, by J. Neils Thompson and W. D. Ramey, 1946.

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*Out of print.

†Single copies of available regular bulletins may be obtained free of charge from the Bureau of Engineering Research, 104 Engineering Building, Austin 12, Texas. Additional copies of regular bulletins and all copies of special bulletins may be purchased at 50 cents each.

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